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DIURNAL SURVEY OF THE THERMOSPHERE
(Final Report)

Prepared under Contract No. NAS 8-20232 by
D. R. Taeusch, G. R. Carignan, A. F. Nagy,
and H. B. Niemann

THE UNIVERSITY OF MICHIGAN

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama

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For

Aero-Astroynamics Laboratory

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

FOREWORD

This report presents atmospheric information that was obtained from eight high-altitude rocket observations. The University of Michigan launched the probes and reduced the resulting data under MSFC Contract No. NAS8-20232. The NASA Contract Monitor was Mr. Robert E. Smith of the Aerospace Environment Division, Aero-Astroynamics Laboratory, Marshall Space Flight Center, Alabama.

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Just recognition of those of the Space Physics Research Laboratory of the University of Michigan who have contributed to the success of this effort would require the personnel list of some 100 employees; however, some of those with specific responsibilities are listed below:

Campbell, B. J.	Design Draftsman
Carter, M. F.	Data Analyst
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Grim, G. K.	Support Electronics Engineer
Halpin, R.	Technician
Kennedy, B. C.	Omegatron Engineer
Lee, T. B.	Electron Temperature Probe Engineer
Maurer, J. C.	Payload Engineer
McCormick, D.	Machinist
Poole, G.	Head Programmer
Simmons, R. W.	Data Processing Manager
Street, M. D.	Technician

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1. INTRODUCTION

The results of the launchings of eight Marshall-University of Michigan Probes (MUMP), Nike-Tomahawk sounding rocket payloads are summarized in this report. The MUMP is similar to the Thermosphere Probe (TP), described by Spencer, Brace, Carignan, Taeusch and Niemann (1965), which was developed by the Space Physics Research Laboratory of The University of Michigan jointly with the Goddard Space Flight Center, Laboratory for Atmospheric and Biological Science. The MUMPS were developed by the Space Physics Research Laboratory for the Marshall Space Flight Center, Aero-Astroynamics Laboratory.

The purpose of the payloads was to study the variability of the earth's atmospheric parameters in the altitude region between 120 and 350 km. The payloads described herein each included an omegatron mass analyzer (Niemann and Kennedy, 1966), an electron temperature probe (Spencer, Brace and Carignan, 1962), and an aspect determination system consisting principally of a lunar or a solar sensor. This complement of instruments permitted the determination of the molecular nitrogen density and temperature, the electron density and temperature, and the ion density in the altitude range of approximately 140 to 320 km over Cape Kennedy, Florida.

Six of the MUMP payloads described herein were launched on January 24, 1967, for the purpose of establishing the diurnal variation of the thermosphere under relatively quiet solar activity levels. The additional two payloads were launched on April 25, 1967, as a follow-on day-night pair to reestablish the maximum-minimum density and temperature values for this day.

A general description of the payload kinematics, the orientation analysis, and the technique for the reduction of the data is given by Taeusch, Carignan, Niemann and Nagy (1965). The reduction of the data was performed at the Space Physics Research Laboratory and the results are included in the present report.

2. BACKGROUND FOR THE EXPERIMENT

2.1 NEUTRAL PARTICLES

It has been established that the atmospheric parameters above an altitude of 100 km vary temporarily because of the variable nature of the solar energy input. The primary variations are periodic following the eleven-year sunspot cycle of our sun, the twenty-four hour diurnal cycle of our rotating earth, and the yearly seasonal cycle due to the latitude change of the subsolar point on earth. Also, two secondary variations have been observed. A twenty-seven day variation has been observed by Jacchia (1963) and has been correlated with the solar decimeter flux and the twenty-seven day rotational period of the sun. A semiannual variation, observed by Paetzold and Zschorner (1960) and by Jacchia (1964), is believed to be due to changes in atmospheric circulation when the subsolar point is near the equator (solstices) (Johnson, 1964).

In terms of the magnitudes of the periodic variations, the eleven-year solar cycle dominates the general atmospheric behavior. Jacchia (1964) reports that the maximum daytime exospheric temperature varies from about 2100°K to about 800°K during the five-and-one-half year interval from maximum to minimum solar activity. The effect of this temperature variation on the atmospheric density is large and variable with altitude, since the scale heights of the constituents change by about a factor of 2.6 during this time.

The diurnal variation in temperature depends upon the latitude and the time of year; however, Jacchia (1964) has stated that the maximum variation has been observed to be approximately 30 per cent from subsolar to antisolar locations on earth and that this diurnal percentage variation is relatively constant for all levels of solar activity.

The observed semiannual temperature variations are on the order of 15 to 20 per cent with the July minimum deeper than the January minimum and the October maximum higher than the April maximum because of a superimposed "annual" effect (Jacchia, 1964). The twenty-seven day variation is on the order of 10 per cent at low latitudes which makes it difficult to observe during periods of variable solar activity.

An attempt to describe the above mentioned variations usually results in a "model" atmosphere, which, for the thermosphere, predicts the diurnal variation of atmospheric parameters for various solar activity levels. Most of the models to date are based on satellite drag data, because of the limited number of measurements by other means. Therefore, the models reflect variations as deduced from these data (Jacchia, 1960; Jacchia, 1961; Harris and Priester, 1964; McElroy, 1964; CIRA, 1965). The major problem to date is that the data on which the models are based, yield total density and temperature as the derived quantities. Therefore, model composition values are deduced from

assumed diffusion levels and assumed total densities well below the lowest altitude where drag data are available. The required assumptions are usually in the form of establishing a constant pressure, temperature, density, and composition at 120 km for all times of day and all levels of solar activity. These assumptions cause relatively small predicted variation in densities, during all variable conditions, up to about 200 km. Undoubtedly these predictions do not give a good physical picture of the real atmospheric behavior at altitudes between 120 and 200 km, as is borne out by recent direct measurements utilizing the Thermosphere Probe (Spencer, et al., 1965a,b). Therefore, it is apparent that the description of atmospheric behavior in the thermosphere must consider variability of the parameters at 120 km and lower.

With these facts in mind, more measurements of atmospheric parameters in the 120 to 300 km region are required, if the variability in this region is to be understood. To date, aeronomy satellites have not been used to measure parameters in the lower region because of the resulting shortened lifetime. Also, satellite measurements do not provide good altitude-density profiles. Instrumented sounding rockets provide the desired data essentially only for one time of day at one geographical location. Separating the various effects previously discussed from data obtained at different times of year, day, latitude, etc., is an almost impossible task; and, therefore, a problem exists of how best to utilize a given payload to provide data of maximum usefulness.

Measurements to be made in the next year or so will not be capable in themselves of yielding information on the eleven-year solar cycle effect. Therefore, it is reasonable to attempt to make all measurements when solar activity is at the same level for each; thus, only the diurnal, the semi-annual, and the seasonal variations remain to be investigated. Of these, the diurnal variation is the most significant. Measurements of atmospheric parameters over the time period of one earth rotation would yield much information bearing on the atmospheric time constant and response to the energy input which, in turn, bears on currently assumed rate coefficients for the various physical processes.

Measurements of the density profiles of neutral nitrogen yield neutral particle temperature with an estimated error of ± 5 per cent (Spencer, et al., 1965a,b), if one assumes that hydrostatic equilibrium exists. Since a discrepancy exists between model diurnal variations of temperature as deduced from satellite drag data, (Jacchia, 1965a,b; Harris and Priester, 1964), the sounding rocket techniques should be able to add significantly to the value of the extensive drag results by yielding better diurnal temperature variation information for input to future models.

2.2 CHARGED PARTICLES

Studies of the diurnal behavior of the electron densities in the E and bottomside F-region began with the introduction of the ionosonde

many years ago. The advent of direct probings by rockets and satellites provided the opportunity of making detailed density measurements in the D, E, and lower F-region and provided the first opportunity for measurements in the topside ionosphere. Rocket and satellite-borne Langmuir probes were also the first to make measurements of the electron and ion temperatures in the ionosphere (Krassovsky, 1959; Boggess, et al., 1959; Bourdeau, et al., 1962; Nagy, et al., 1963). It is difficult to establish a true diurnal pattern by using data from satellite-borne experiments, because of the intricacies involved in separating latitude, longitude, altitude, and seasonal effects in the results obtained. It is also difficult to obtain a complete diurnal pattern by using data from rockets flown to date, because it is necessary to combine the results from numerous flights, carried out on different days sometimes under widely varying conditions. The incoherent backscatter technique (e.g., Evans, 1965a) is very well suited for diurnal measurements of electron density and electron and ion temperature. These measurements are, however, usually restricted to altitudes above about 200 km and have a height resolution of about 50 km. The usual time taken for the measurements of one complete profile by this technique is in the order of one hour, although consecutive measurements have been made during an eclipse (Evans, 1965b) in 15-minute time intervals.

The purpose of the rocket program, which is described in this report, was to obtain information on the diurnal variation of the electron temperature and density as well as neutral particle temperature and density in an altitude range where good diurnal measurements are lacking. By the appropriate selection of the launch times, it was also possible to investigate a number of specific problems, which will be discussed briefly in Section 9.

3. GENERAL FLIGHT INFORMATION

The general flight information for the MUMP payloads is tabulated below. The Table of Events for each flight, which follows on the next pages, gives flight times and altitudes of significant events occurring during the flight. Some of these have been estimated and are so marked. The others have been obtained from the telemetry records and radar trajectories, where applicable.

Launch Date: January 24, 1967

Location: Cape Kennedy, Florida

Latitude: 28° 27.5'N

Longitude: 80° 31.5'W

MUMP NO.	Test Number	(EST) Local Time	G.M. Time	Local Solar Time	Solar Zenith χ Angle
8	ETR-1474	0400	0900	0326	132.4°
6	ETR-1828	0651	1151	0618	95.6°
3	ETR-1165	1009	1509	0935	60.0°
1	ETR-0381	1434	1934	1400	55.5°
2	ETR-0611	1750	2250	1712	90.0°
7	ETR-0851	2200	0300	2126	143.7°

Launch Date: April 25, 1967

MUMP NO.	Test Number	(EST) Local Time	G.M. Time	Local Solar Time	Solar Zenith χ Angle
4	ETR-1942	0130	0630	0055	135.3°
5	ETR-4803	1400	1900	1325	27.8°

TABLE I
TABLE OF EVENTS

ETR 0381

Mump 1

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.587	1.4 (est.)
2nd Stage Ignition	12.137	7.0 (est.)
2nd Stage Burnout	21.158	20.7 (est.)
Despin	43.083	71.3
TP Ejection	44.878	75.2
Omegatron Breakoff	79.904	144.2
Omegatron Filaments On. M28	80.440	146.7
Peak Altitude	287.74	336.12
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	547.0	39.0
<hr/>		
Launch Date:	January 24, 1967	
Launch Time:	19:33:59.940 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	336.12 km	
Horizontal Velocity:	471.10 m/sec	
Flight Time:	287.74 sec	
TP Motion:		
Tumble Period:	1.514 sec	
Roll Rate	-50 deg/sec	

TABLE II
TABLE OF EVENTS
ETR 0611
MUMP 2

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	4.0 (est.)	1.6 (est.)
2nd Stage Ignition	13.0 (est.)	7.2 (est.)
2nd Stage Burnout	21.5 (est.)	20.5 (est.)
Despin	41.0 (est.)	66. (est.)
TP Ejection	42.862	69.7
Omegatron Breakoff	78.320	139.5
Omegatron Filaments On. M28	78.704	140.2
Peak Altitude	279.96	319.58
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	541.0	24.0
<hr/>		
Launch Date:	January 24, 1967	
Launch Time:	22:50:00.428 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	319.58 km	
Horizontal Velocity:	457.24 m/sec	
Flight Time:	279.96 sec	
TP Motion:		
Tumble Period:	3.32 sec	
Roll Rate:	0 deg/sec	

TABLE III
TABLE OF EVENTS
ETR 1165
MUMP 3

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.45 (est.)	1.7 (est.)
2nd Stage Ignition	12.002	7.2 (est.)
2nd Stage Burnout	20.434	20.6 (est.)
Despin	43.352	72.0 (est.)
TP Ejection	44.822	76.0 (est.)
Omegatron Breakoff	77.532	138.8
Omegatron Filaments On. M28	78.335	140.1
Peak Altitude	382.61	324.22
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	543.0	30.0
<hr/>		
Launch Date:	January 24, 1967	
Launch Time:	15:08:54.448 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	324.22 km	
Horizontal Velocity:	551.69 m/sec	
Flight Time:	282.61 sec	
TP Motion:		
Tumble Period:	1.086 sec	
Roll Rate:	-125 deg/sec	

TABLE IV
TABLE OF EVENTS
ETR 1942
MUMP 4

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.524	1.4 (est.)
2nd Stage Ignition	12.0 (est.)	7.0 (est.)
2nd Stage Burnout	21.926	21.0 (est.)
Despin	43.734	71.9
TP Ejection	46.557	78.2
Omegatron Breakoff	78.121	142.0
Omegatron Filaments On. M28	78.719	143.1
Peak Altitude	287.971	337.511
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	546.0	43.0
<hr/>		
Launch Date:	April 25, 1967	
Launch Time:	06:30:00.499 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	337.511 km	
Horizontal Velocity:	384.41 m/sec	
Flight Time:	287.971 sec	
TP Motion:		
Tumble Period:	1.160 sec	
Roll Rate:	0 deg/sec	

TABLE V
TABLE OF EVENTS
ETR 4803
MUMP 5

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.574	1.4 (est.)
2nd Stage Ignition	12.480	7.0 (est.)
2nd Stage Burnout	21.398	21.0 (est.)
Despin	44.5 (est.)	74.7 (est.)
TP Ejection	47.2 (est.)	80.6 (est.)
Omegatron Breakoff	76.704	139.9
Omegatron Filaments On. M28	77.373	141.1
Peak Altitude	286.68	334.73
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	548.0	34.0
<hr/>		
Launch Date:	April 25, 1967	
Launch Time:	19:00:00.110 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	334.733 km	
Horizontal Velocity:	419.65 m/sec	
Flight Time:	286.680 sec	
TP Motion:		
Tumble Period:	1.497 sec	
Roll Rate:	-46 deg/sec	

TABLE VI
TABLE OF EVENTS
ETR 1828
MUMP 6

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.830	2.0 (est.)
2nd Stage Ignition	12.160	7.2 (est.)
2nd Stage Burnout	20.878	20.8 (est.)
Despin	43.292	71.5 (est.)
TP Ejection	45.286	76.0 (est.)
Omegatron Breakoff	75.697	135.0
Omegatron Filaments On. M28	76.435	136.6
Peak Altitude	283.190	324.8
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	548.0	24.0
<hr/>		
Launch Date:	January 24, 1967	
Launch Time:	11:51:26.420 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	324.82	km
Horizontal Velocity:	574.79	m/sec
Flight Time:	283.190	sec
TP Motion:		
Tumble Period:	1.137	sec
Roll Rate:	-50	deg/sec

TABLE VII
TABLE OF EVENTS
ETR 0851
MUMP 7

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.4 (est.)	1.4 (est.)
2nd Stage Ignition	12.000	7.0 (est.)
2nd Stage Burnout	21.0 (est.)	20.7 (est.)
Despin	43.0 (est.)	70.2
TP Ejection	45.751	76.2
Omegatron Breakoff	66.994	119.3
Omegatron Filaments On. M28	67.681	121.9 (est.)
Peak Altitude	283.97	327.3
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	539.0	39.0
Launch Date:	January 25, 1967	
Launch Time:	3:00:00.059 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	327.3 km	
Horizontal Velocity:	525.75 m/sec	
Flight Time:	283.97 sec	
TP Motion:		
Tumble Period:	1.511 sec	
Roll Rate:	-200 deg/sec	

TABLE VIII
TABLE OF EVENTS
ETR 1474
MUMP 8

Event	Flight Time (sec)	Altitude (km)
Lift Off	0	0
1st Stage Burnout	3.122	1.4 (est.)
2nd Stage Ignition	12.265	7.2 (est.)
2nd Stage Burnout	21.240	20.8 (est.)
Despin	42.898	71.2 (est.)
TP Ejection	45.301	75.8 (est.)
Omegatron Breakoff	78.271	140.3
Omegatron Filaments On. M28	78.968	141.6
Peak Altitude	282.928	325.36
Omegatron to Mass 16	Not Applicable	
Omegatron to Mass 32	Not Applicable	
Omegatron to Mass 28	Not Applicable	
L.O.S.	539.0	36.0
<hr/>		
Launch Date:	January 24, 1967	
Launch Time:	9:00:00.252 GMT	
Location:	Cape Kennedy, Florida	
Apogee Parameters:		
Altitude:	325.36	km
Horizontal Velocity:	506.44	m/sec
Flight Time:	282.928	sec
TP Motion:		
Tumble Period:	1.546	sec
Roll Rate:	-25	deg/sec

4. LAUNCH VEHICLE

The launch vehicles used for each flight were a two-stage Nike-Tomahawk combination. The first stage, the solid propellant Nike booster, has an average thrust of 49,000 lb and burns for approximately 3.5 sec. The Nike, 135 in. long and 16.5 in. in diameter weighs 1,338 lb unburned. The center of gravity (CG) was 75.7 in. from the nozzle exit plane (NEP). The second stage, Thiokol's Tomahawk solid propellant motor, has an average thrust of approximately 11,000 lb and burns for about 9 sec. The Tomahawk, 142 in. long and 9 in. in diameter, weighs 530 lb unburned. The CG was 72.125 in. from the NEP. The payloads were 78.4 in. long and weighed 132 lb. The total vehicle was 355 in. long and weighed 2,000 lb. Drawings and photographs of the vehicle are given in Figures 1, 2, and 3.

The predicted performance for the vehicle was 322 km peak altitude at 281 sec flight time. The actual performances were discussed in the previous section.

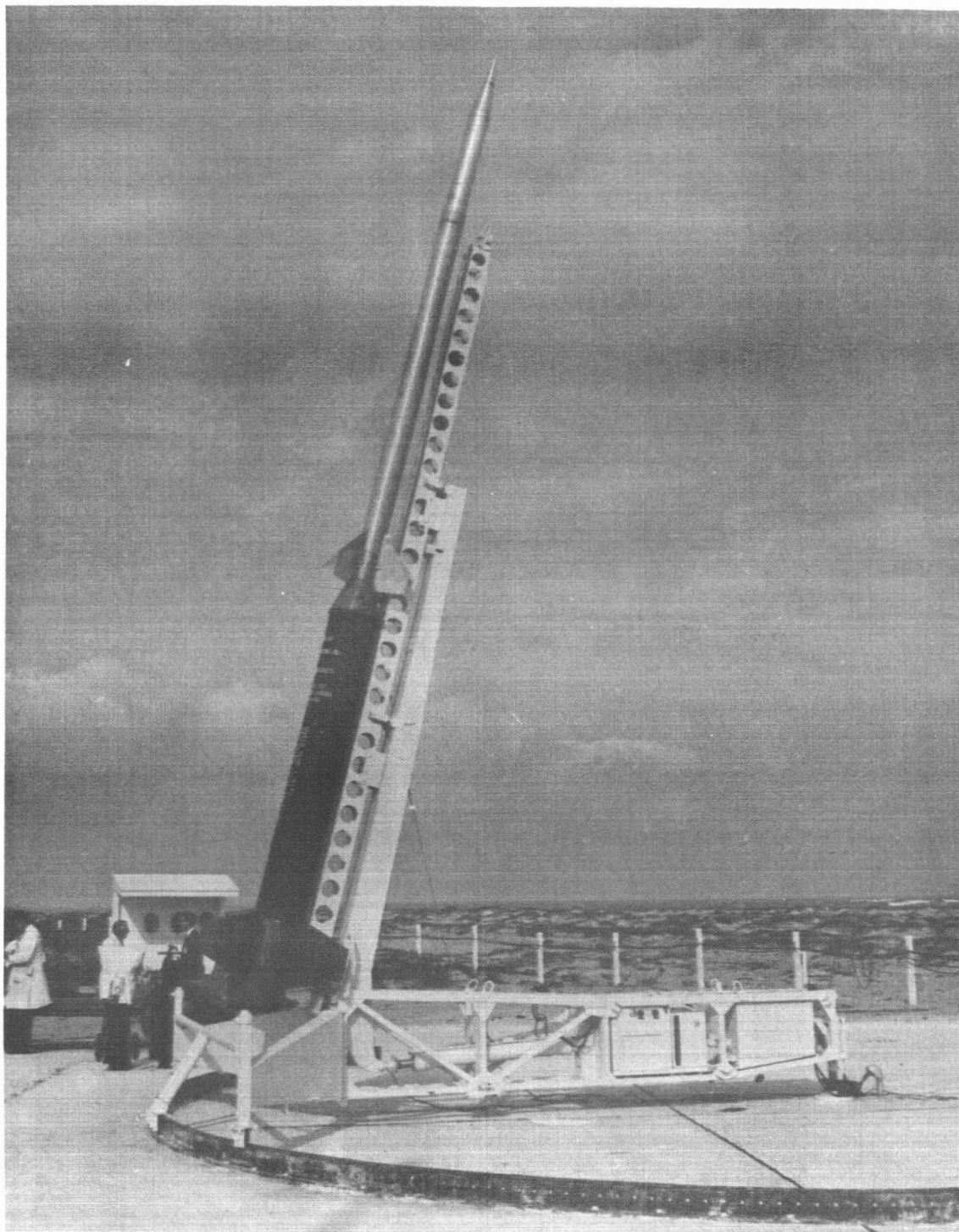
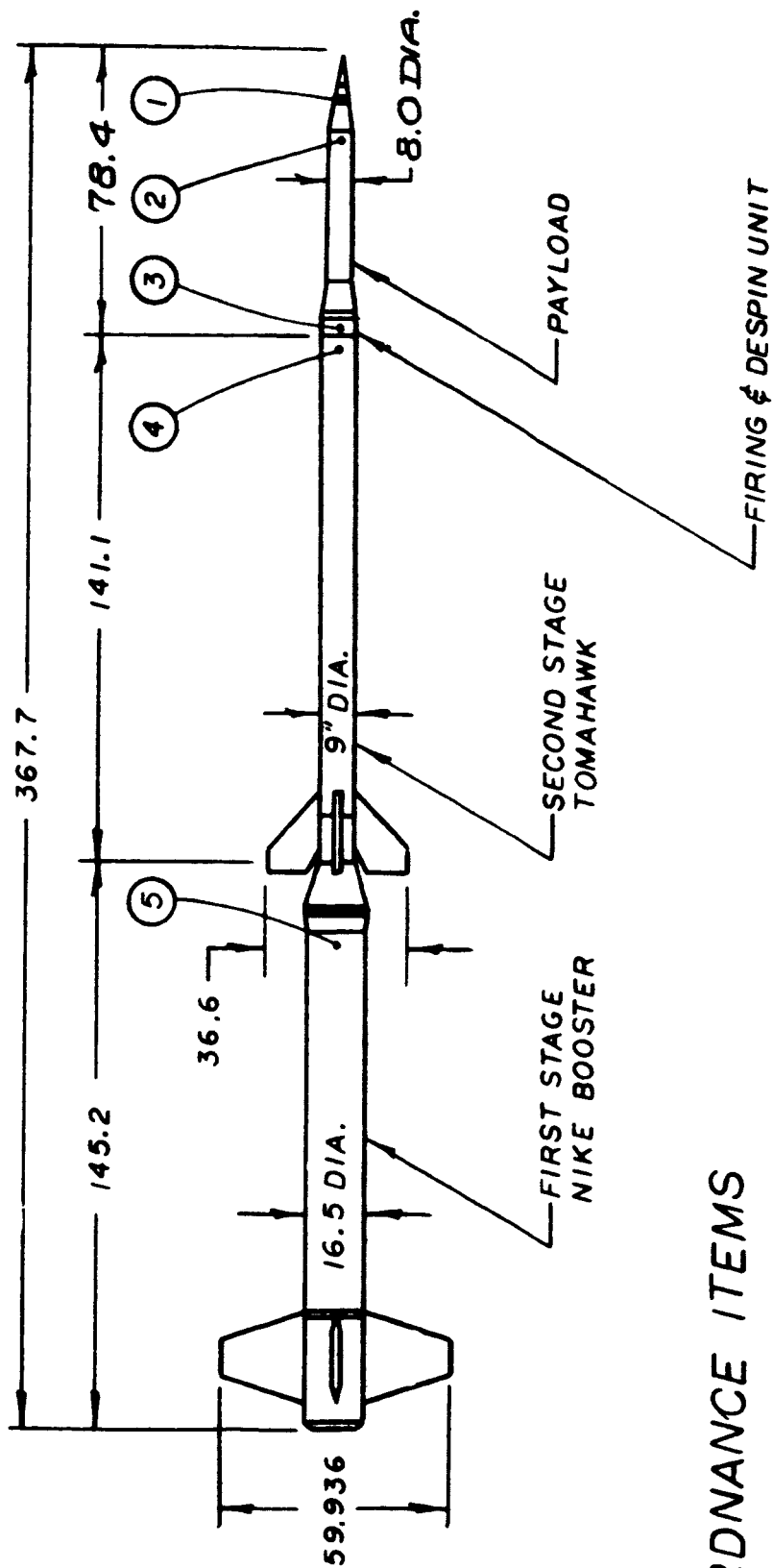


Figure 1. Nike-Tomahawk with MUMP payload.



Figure 2. Nike-Tomahawk with MUMP payload.



ORDNANCE ITEMS

- ① NOSE CONE OPENING PRIMERS.
- ② BREAKOFF LINEAR ACTUATORS
- ③ DESPIN INITIATION PRIMERS
- ④ SECOND STAGE IGNITER
- ⑤ NIKE BOOSTER IGNITER

Figure 3. Nike-Tomahawk dimensions.

5. NOSE CONE

A diagram of a day shot of a typical payload including nose cone, despin mechanisms, and adapter sections is shown in Figure 4. Figure 5 shows a typical payload of a night shot. The weights, dimensions, and instrumentation placement are also given on the figures. Figure 6 is a photograph of the TP in the nose cone. An assembly drawing of the 8" nose cone is given in Figure 7.

The payload is programmed to despin at about 70 km altitude, and the MUMP is ejected and tumbled at about 75 km. The breakoff device is removed at about 110 km, and the omegatron filaments are turned on a few seconds later. The timing for each particular payload has been described previously.

A determination of the total payload moments of inertia, performed at The Bendix Systems Division in Ann Arbor, is included in their report in the appendix. Figures 1 through 3 (Appendix) show the test setup and the instrument package test setup.

NASA	
T.P. NO.	MUMP - (DAY SHOT)
TYPE OF ROCKET	NIKE - TOMAHAWK
DATE OF SHOT	JANUARY 24, 1967
LOCATION	CAPE KENNEDY
TIME	
ALTITUDE	

RESULTS - DATA OK

MISC. NOTES -1. DAY SHOT
OMEG
E.S.P.
-2. O & O OSCILLATORS
REMOVED FROM OSC DECKS
-3. DESPIN FLOWN

SECTION 1

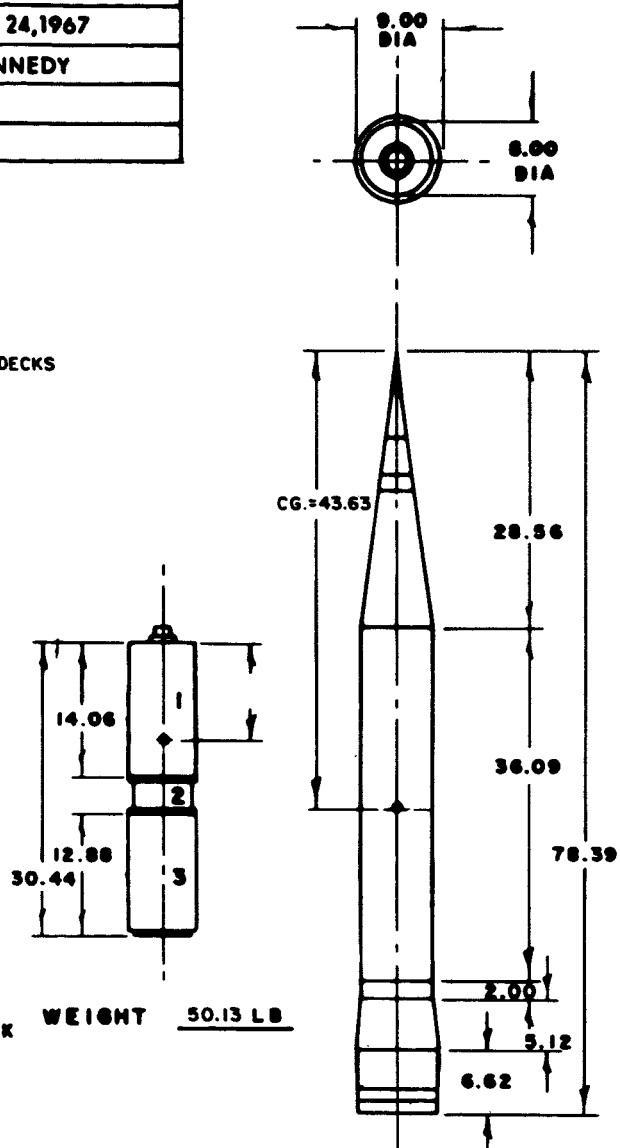
1. OMEG ASS'Y @ B O
2. OMEG ADAPTER
3. OMEG AMP
4. REG DECK
5. OM X 5 DECK.
6. OSC DECK 1
7. OSC DECK 2
8. AUX DECK

SECTION 2

1. 3 ADCOLE ASPECT SENSOR
2. ELECTRONICS FOR SENSOR
3. SINGLE PROBE

SECTION 3

1. TRANSMITTER @ BATT. DECK
2. ESP DECK
3. SCO DECK
4. COMM DECK
5. CONTROL DECK
- 6.



WEIGHT 82.75 LB

TOTAL WEIGHT OF PROBE AND NOSE CONE 132.88 LB

Figure 4. Payload diagram for a day shot.

NASA	
T.P. NO.	MUMP- (NIGHT SHOT)
TYPE OF ROCKET	NIKE - TOMAHAWK
DATE OF SHOT	JANUARY 24, 1967
LOCATION	CAPE KENNEDY
TIME	
ALTITUDE	

RESULTS - DATA OK

MISC. NOTES -1. NIGHT SHOT
OMEG
E.S.P.
-2. O & O² OSCILLATORS
REMOVED FROM OSC DECKS
-3. DESPIN FLOWN

SECTION 1

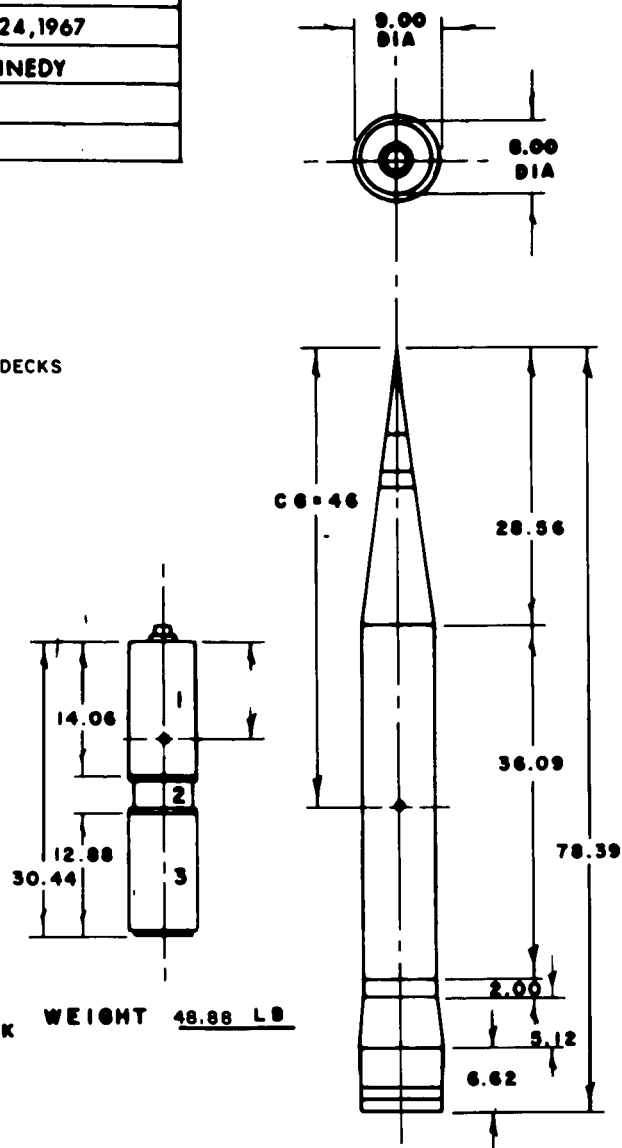
1. OMEG ASS'Y @ 80
2. OMEG ADAPTER
3. OMEG AMP
4. RES DECK
5. OM X S DECK
6. OSC DECK 1
7. OSC DECK 2
8. AUX DECK

SECTION 2

1. SINGLE PROBE

SECTION 3

1. TRANSMITTER @ BATT. DECK
2. ESP DECK
3. SCO DECK
4. COMM DECK
5. CONTROL DECK
6. LUNAR ASPECT SENSOR



TOTAL WEIGHT OF PROBE AND NOSE CONE 131.63 LB

Figure 5. Payload diagram for a night shot.

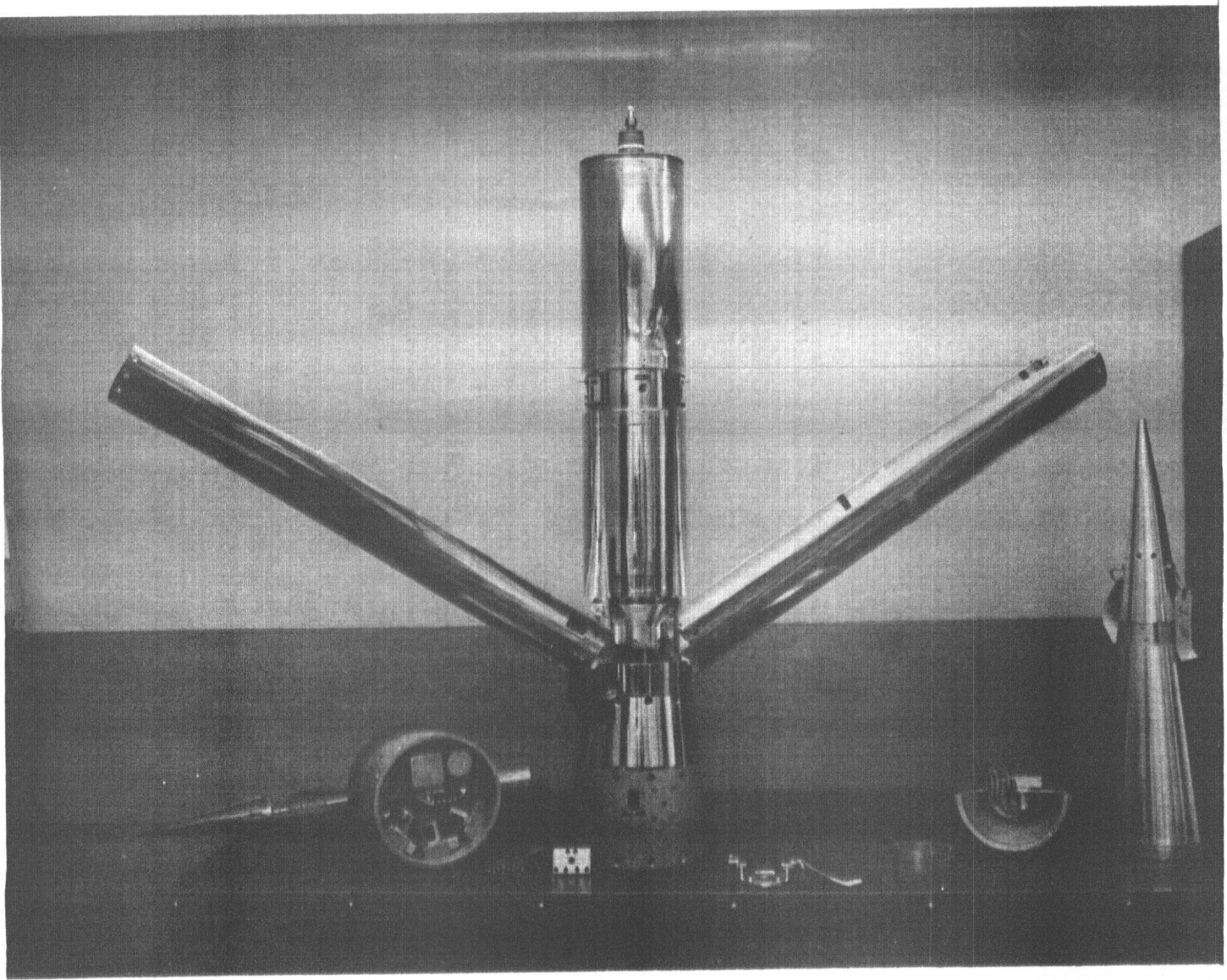


Figure 6. Thermosphere probe in nose cone.

NO.	DESCRIPTION	QTY.	UNIT	REMARKS
1	NOSE CONE	1	PC	
2	NOSE CONE	1	PC	
3	NOSE CONE	1	PC	
4	NOSE CONE	1	PC	
5	NOSE CONE	1	PC	
6	NOSE CONE	1	PC	
7	NOSE CONE	1	PC	
8	NOSE CONE	1	PC	
9	NOSE CONE	1	PC	
10	NOSE CONE	1	PC	
11	NOSE CONE	1	PC	
12	NOSE CONE	1	PC	
13	NOSE CONE	1	PC	
14	NOSE CONE	1	PC	
15	NOSE CONE	1	PC	
16	NOSE CONE	1	PC	
17	NOSE CONE	1	PC	
18	NOSE CONE	1	PC	
19	NOSE CONE	1	PC	
20	NOSE CONE	1	PC	
21	NOSE CONE	1	PC	
22	NOSE CONE	1	PC	
23	NOSE CONE	1	PC	
24	NOSE CONE	1	PC	
25	NOSE CONE	1	PC	
26	NOSE CONE	1	PC	
27	NOSE CONE	1	PC	
28	NOSE CONE	1	PC	
29	NOSE CONE	1	PC	
30	NOSE CONE	1	PC	
31	NOSE CONE	1	PC	
32	NOSE CONE	1	PC	
33	NOSE CONE	1	PC	
34	NOSE CONE	1	PC	
35	NOSE CONE	1	PC	
36	NOSE CONE	1	PC	
37	NOSE CONE	1	PC	
38	NOSE CONE	1	PC	
39	NOSE CONE	1	PC	
40	NOSE CONE	1	PC	
41	NOSE CONE	1	PC	
42	NOSE CONE	1	PC	
43	NOSE CONE	1	PC	
44	NOSE CONE	1	PC	
45	NOSE CONE	1	PC	
46	NOSE CONE	1	PC	
47	NOSE CONE	1	PC	
48	NOSE CONE	1	PC	
49	NOSE CONE	1	PC	
50	NOSE CONE	1	PC	
51	NOSE CONE	1	PC	
52	NOSE CONE	1	PC	
53	NOSE CONE	1	PC	
54	NOSE CONE	1	PC	
55	NOSE CONE	1	PC	
56	NOSE CONE	1	PC	
57	NOSE CONE	1	PC	
58	NOSE CONE	1	PC	
59	NOSE CONE	1	PC	
60	NOSE CONE	1	PC	
61	NOSE CONE	1	PC	
62	NOSE CONE	1	PC	
63	NOSE CONE	1	PC	
64	NOSE CONE	1	PC	
65	NOSE CONE	1	PC	
66	NOSE CONE	1	PC	
67	NOSE CONE	1	PC	
68	NOSE CONE	1	PC	
69	NOSE CONE	1	PC	
70	NOSE CONE	1	PC	
71	NOSE CONE	1	PC	
72	NOSE CONE	1	PC	
73	NOSE CONE	1	PC	
74	NOSE CONE	1	PC	
75	NOSE CONE	1	PC	
76	NOSE CONE	1	PC	
77	NOSE CONE	1	PC	
78	NOSE CONE	1	PC	
79	NOSE CONE	1	PC	
80	NOSE CONE	1	PC	
81	NOSE CONE	1	PC	
82	NOSE CONE	1	PC	
83	NOSE CONE	1	PC	
84	NOSE CONE	1	PC	
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91	NOSE CONE	1	PC	
92	NOSE CONE	1	PC	
93	NOSE CONE	1	PC	
94	NOSE CONE	1	PC	
95	NOSE CONE	1	PC	
96	NOSE CONE	1	PC	
97	NOSE CONE	1	PC	
98	NOSE CONE	1	PC	
99	NOSE CONE	1	PC	
100	NOSE CONE	1	PC	

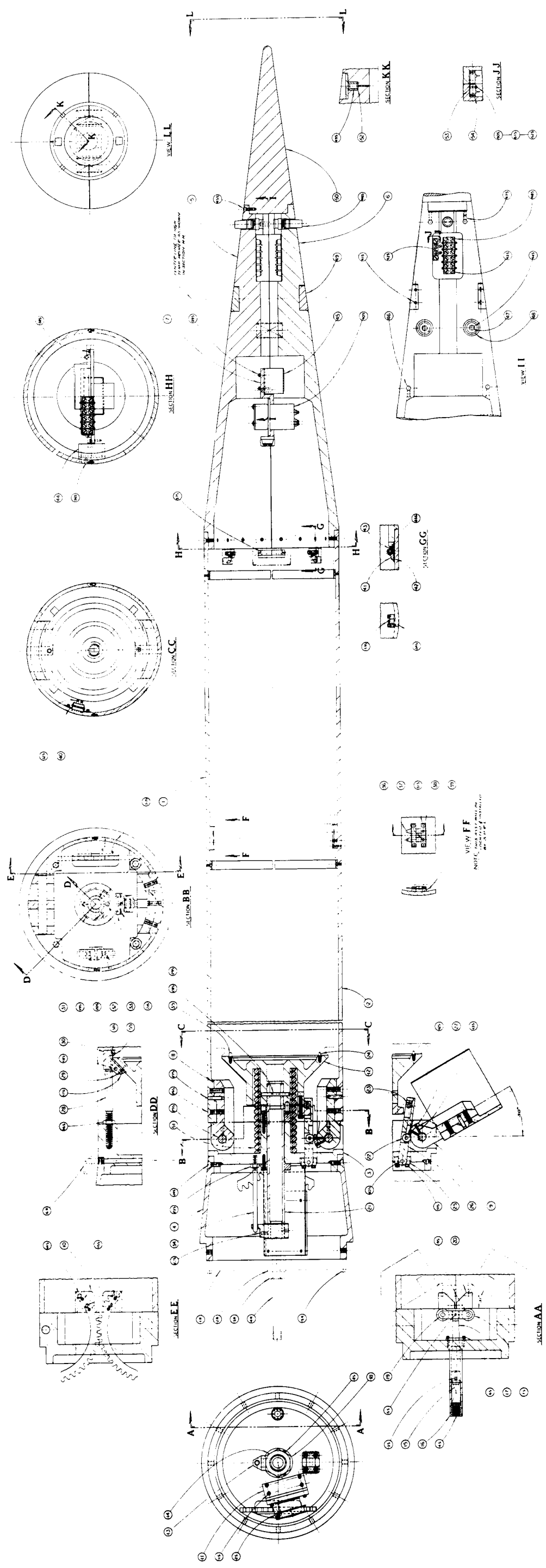


Figure 7. Assembly drawing, 8-in. nose cone.

6. MARSHALL-UNIVERSITY OF MICHIGAN PROBE (MUMP)

The MUMP, a cylinder 30.44 in. long and 7.25 in. in diameter, weighs 50 lb. The prime instruments for this payload are an omegatron mass analyzer and an electron temperature probe unit. Supporting instrumentation includes a lunar or solar aspect sensor for the determination of the TP aspect. The diagram in Figure 8 shows the instrumentation and supporting electronics location, and Figure 9 shows the block diagram. Figure 10 is a picture of the completely assembled TP.

6.1 OMEGATRON

The omegatron used in these payloads was of the type described by Niemann and Kennedy (1966). An expanded view of the system is shown in Figure 11. Tables 9 through 16 list the operating parameters of the gauge and associated electronics. The characteristics of the linear electrometer amplifier current detector, used to monitor the omegatron output current, are also listed.

These omegatrons are essentially identical to those flown previously on NASA's 18.02 and 18.03 (Taeusch and Carignan, 1966a,b). The breakoff unit, omegatron envelope, and omegatron magnet assembly are shown in Figures 12, 13, and 14.

The calibrations of all omegatrons were performed in December and January preceding the launch. The vacuum system used could accommodate four of the flight gauges at one time plus reference Bayard-Alpert ionization gauges used as secondary standards.

A two-stage oil diffusion pump vacuum system was used as a pressure calibration system. To obtain extremely low oil backstreaming, the second stage oil diffusion pump was equipped with a cold cap and two six-inch Granville-Phillips liquid N₂ cold traps. A typical background pressure, after the system has been baked at 360°C for 48 hours, was about 2×10^{-10} torr. Dry nitrogen was leaked into the system as a calibration gas. Calibration data were taken from background pressures to 3×10^{-5} torr. Above this pressure the omegatron becomes highly nonlinear.

Figure 15 is a photograph of an actual calibration set-up. Four omegatrons were calibrated at a time against four Bayard-Alpert ionization gauges (B-A gauges). The B-A gauges were used as secondary references. Two B-A gauges were previously calibrated by the Ball Brothers Corporation against a McLeod gauge. In order to provide continuity, one other gauge was used as reference from previous calibrations of earlier omegatron experiments. Since only four omegatrons could be calibrated at one time, to obtain an accurate

relative calibration of the omegatrons, combinations in pairs were used where each group was calibrated twice.

Gauge outputs and all critical supply voltages were printed by a datum system employing a 50 channel time multiplexer, an NLS integrating digital voltmeter, and a Hewlett-Packard printer. Also, all gauge outputs were analog-recorded on an eight-channel Sanborn recorder. After calibration, the omegatrons were prepared for pinch-off in pairs, and their output currents were compared at two different pressures. Thus it was determined that no damage had been done to the instrument during reassembly. Calibration curves of the omegatrons are shown in Figures 16-23. The omegatron currents were plotted against particle number densities which were calculated from the reference pressure values.

TABLE IX
OMEGATRON DATA

ETR 0381

MUMP 1

Omegatron Gauge Parameters:

Beam Current:	2.02	μamps
Electron Collector Bias:	77.65	volts
Filament Bias:	-91.50	volts
Cage Bias:	-0.194	volts
Top Bias:	-0.609	volts
RF Amplitude:		
M28	3.70	V _{p-p}
RF Frequency:		
M28	144.93	kHz

Monitor

Filament		
OFF:	0.114	V
ON:	3.183	V (steady)
Beam		
OFF:	0.266	V
ON:	3.114	V
Thermistor Pressure	Filament OFF:	4.368V
(zero pressure)	Filament ON:	4.013V
Bias:	4.024	V
RF:		
M28	3.740	V

Calibration

Sensitivity:	2.00×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	1.3×10^{-5}	torr

TABLE IX (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	8.645×10^9	5.066
2	0.7 v	2.350×10^{10}	5.066
3	1.4 v	6.388×10^{10}	5.066
4	2.1 v	1.832×10^{11}	5.067
5	2.8 v	5.128×10^{11}	5.068
6	3.5 v	1.434×10^{12}	5.0714
7	4.2 v	4.047×10^{12}	5.0807
8	4.9 v	9.700×10^{12}	5.106

calibration voltage 0.571 v

Miscellaneous

+28 power current all on: 300ma
 Preflight gauge pressure (N_2): 3.45×10^{-5} torr
 Magnetic field strength: 2700 gauss

TABLE X
OMEGATRON DATA

ETR 0611

MUMP 2

Omegatron Gauge Parameters

Beam Current:	2.005	μamps
Electron Collector Bias:	77.22	volts
Filament Bias:	-92.87	volts
Cage Bias:	-0.209	volts
Top Bias:	-0.609	volts
RF Amplitude:		
M28	4.00	V _{p-p}
RF Frequency:		
M28	143.59	kHz

Monitor

Filament		
OFF:	0.106	V
ON:	3.091	V
Beam		
OFF:	0.678	V
ON:	2.916	V
Thermistor Pressure	Filament OFF:	2.140V
(zero pressure)	Filament ON:	2.000V
Bias:	4.082	V
RF:		
M28	3.694	V

Calibration

Sensitivity:	1.82×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	9×10^{-6}	torr

TABLE X (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	4.884
2	0.7 v	2.479×10^{10}	4.884
3	1.4 v	6.738×10^{10}	4.884
4	2.1 v	1.832×10^{11}	4.884
5	2.8 v	4.979×10^{11}	4.885
6	3.5 v	1.353×10^{12}	4.887
7	4.2 v	4.047×10^{12}	4.897
8	4.9 v	1.00×10^{13}	4.902

calibration voltage 0.524 v

Miscellaneous

+28 power current all on: 370 ma
 Preflight gauge pressure (N_2): 5.9×10^{-5} torr
 Magnetic field strength: 2680 gauss

TABLE XI
OMEGATRON DATA

ETR 1165

MUMP 3

Omegatron Gauge Parameters

Beam Current:	1.99	μamps
Electron Collector Bias:	78.24	volts
Filament Bias:	-92.10	volts
Cage Bias:	-0.204	volts
Top Bias:	-0.602	volts
RF Amplitude:		
M28	4.00	V
RF Frequency:		p-p
M28	140.06	kHz

Monitor

Filament		
OFF:	0.108	V
ON:	3.199	V
Beam		
OFF:	0.350	V
ON:	3.700	V
Thermistor Pressure:	Filament OFF:	2.333V
(zero pressure)	Filament ON:	2.110V
Bias:	4.129	V
RF:		
M28	3.548	V

Calibration

Sensitivity:	1.96×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	1.2×10^{-5}	torr

TABLE XI (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	8.483×10^9	4.980
2	0.7 v	2.306×10^{10}	4.980
3	1.4 v	6.268×10^{10}	4.980
4	2.1 v	1.832×10^{11}	4.981
5	2.8 v	5.049×10^{11}	4.981
6	3.5 v	1.361×10^{12}	4.987
7	4.2 v	3.746×10^{12}	5.000
8	4.9 v	9.538×10^{12}	5.029

calibration voltage 0.577 volts

Miscellaneous

+28 power current all on: 375 ma
 Preflight gauge pressure (N_2): 5.6×10^{-6} torr
 Magnetic field strength: 2620 gauss

TABLE XII
OMEGATRON DATA

ETR 1494

MUMP 4

Omegatron Gauge Parameters

Beam Current:	2.00	μamps
Electron Collector Bias:	77.58	volts
Filament Bias:	-89.45	volts
Cage Bias:	-.2010	volts
Top Bias:	-.599	volts
RF Amplitude:		
M28	3.90	V _{p-p}
RF Frequency:		
M28	136.68	kHz

Monitor

Filament		
OFF:	.1104	V
ON:	3.165	V
Beam		
OFF:	0.270	V
ON:	3.454	V
Thermistor Pressure:	Filament OFF:	2.086V
(zero pressure)	Filament ON:	1.917V
Bias:	4.093	V
RF:		
M28	3.698	V

Calibration

Sensitivity:	2.03×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	7×10^{-6}	torr

TABLE XII (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	5.003
2	0.7 v	2.479×10^{10}	5.003
3	1.4 v	6.738×10^{10}	5.003
4	2.1 v	1.832×10^{11}	5.0015
5	2.8 v	4.979×10^{11}	4.999
6	3.5 v	1.353×10^{12}	4.987
7	4.2 v	3.679×10^{12}	4.973
8	4.9 v	1.000×10^{13}	4.918

calibration voltage 0.663 v

Miscellaneous

+29 power current all on: 320 ma
 Preflight gauge pressure (N_2): 14×10^{-5} torr
 Magnetic field strength: 2540 gauss

TABLE XIII
OMEGATRON DATA

ETR 4803

MUMP 5

Omegatron Gauge Parameters

Beam Current:	2.005	μamps
Electron Collector Bias:	77.45	volts
Filament Bias:	-89.27	volts
Cage Bias:	-0.204	volts
Top Bias:	-0.604	volts
RF Amplitude:		
M28	3.98	V
RF Frequency:		p-p
M28	143.43	kHz

Monitor

Filament		
OFF:	0.115	V
ON:	3.036	V
Beam		
OFF:	0.525	V
ON:	3.471	V
Thermistor Pressure:	Filament OFF:	3.027V
(zero pressure)	Filament ON:	2.860V
Bias:	4.115	V
RF:		
M28	3.376	V

Calibration

Sensitivity:	1.90×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	6×10^{-6}	torr

TABLE XIII (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	4.964
2	0.7 v	2.479×10^{10}	4.964
3	1.4 v	6.738×10^{10}	4.964
4	2.1 v	1.832×10^{11}	4.963
5	2.8 v	4.979×10^{11}	4.962
6	3.5 v	1.258×10^{12}	4.96
7	4.2 v	3.863×10^{12}	4.950
8	4.9 v	1.130×10^{13}	4.926

calibration voltage 0.586 volts

Miscellaneous

+28 power current all on: 390 ma
 Preflight gauge pressure (N_2): 3.33×10^{-5} torr
 Magnetic field strength: 2660 gauss

TABLE XIV
OMEGATRON DATA

ETR 1828

MUMP 6

Omegatron Gauge Parameters

Beam Current:	2.02	μamps
Electron Collector Bias:	76.5	volts
Filament Bias:	-89.95	volts
Cage Bias:	-0.206	volts
Top Bias:	-0.613	volts
RF Amplitude:		
M28	4.00	V _{p-p}
RF Frequency:		
M28	139.12	kHz

Monitor

Filament		
OFF:	0.113	V
ON:	2.900	V
Beam		
OFF:	0.600	V
ON:	3.880	V
Thermistor Pressure:	Filament OFF:	2.283V
(zero pressure)	Filament ON:	2.136V
Bias:	3.833	V
RF:		
M28	3.797	V

Calibration

Sensitivity:	2.23×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	8×10^{-6}	torr

TABLE XIV (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	5.028
2	0.7 v	2.479×10^{10}	5.028
3	1.4 v	6.738×10^{10}	5.028
4	2.1 v	1.832×10^{11}	5.029
5	2.8 v	5.037×10^{11}	5.030
6	3.5 v	1.435×10^{12}	5.034
7	4.2 v	4.016×10^{12}	5.046
8	4.9 v	1.077×10^{13}	5.073

calibration voltage 0.648 v

Miscellaneous

+28 power current all on: 320 ma
 Preflight gauge pressure (N_2): 3.45×10^{-5} torr
 Magnetic field strength: 2600 gauss

TABLE XV
OMEGATRON DATA

ETR 0851

MUMP 7

Omegatron Gauge Parameters

Beam Current:	1.99	μ amps
Electron Collector Bias:	78.24	volts
Filament Bias:	-92.02	volts
Cage Bias:	-0.205	volts
Top Bias:	-0.601	volts
RF Amplitude:		
M28	4.00	V _{p-p}
RF Frequency:		
M28	143.23	kHz

Monitor

Filament		
OFF:	0.112	V
ON:	3.436	V
Beam:		
OFF:	0.642	V
ON:	3.886	V
Thermistor Pressure:	Filament OFF:	1.842V
(zero pressure)	Filament ON:	1.696V
Bias:	4.099	V
RF:		
M28	3.392	V

Calibration

Sensitivity:	2.03×10^{-5}	amps/torr
Maximum Linear Pressure (5%):	7×10^{-6}	torr

TABLE XV (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	5.062
2	0.7 v	2.479×10^{10}	5.062
3	1.4 v	6.738×10^{10}	5.062
4	2.1 v	1.832×10^{11}	5.062
5	2.8 v	4.979×10^{11}	5.062
6	3.5 v	1.353×10^{12}	5.061
7	4.2 v	4.075×10^{12}	5.061
8	4.9 v	1.123×10^{13}	5.057

calibration voltage 0.622 v

Miscellaneous

+28 power current all on: 400 ma
 Preflight gauge pressure (N_2): 2.5×10^{-5} torr
 Magnetic field strength: 2660 gauss

TABLE XVI
OMEGATRON DATA

ETR 1474

MUMP 8

Omegatron Gauge Parameters

Beam Current:	2.00	μamps
Electron Collector Bias:	78.70	volts
Filament Bias:	-89.80	volts
Cage Bias:	-.197	volts
Top Bias:	-.596	volts
RF Amplitude:		
M28	4.00	V
RF Frequency:		p-p
M28	143.42	kHz

Monitor

Filament		
OFF:	.1025	V
ON:	3.324	V
Beam		
OFF:	.8460	V
ON:	4.129	V
Thermistor Pressure:	Filament OFF:	2.119V
(zero pressure)	Filament ON:	1.874V
Bias:	4.188	V
RF:		
M28	3.625	V

Calibration

Sensitivity:	2.12×10^{-5} amps/torr
Maximum Linear Pressure (5%):	9×10^{-6} torr

TABLE XVI (CONCLUDED)

Electrometer Amplifier

<u>Range</u>	<u>Range Indicator</u>	<u>Range Resistor</u>	<u>M28ZPV</u>
1	0.0 v	9.119×10^9	4.978
2	0.7 v	2.479×10^{10}	4.978
3	1.4 v	6.738×10^{10}	4.978
4	2.1 v	1.832×10^{11}	4.9771
5	2.8 v	4.953×10^{11}	4.9715
6	3.5 v	1.330×10^{12}	4.9712
7	4.2 v	3.374×10^{12}	4.9613
8	4.9 v	9.087×10^{12}	4.954

calibration voltage 0.459 v

Miscellaneous

+28 power current all on: 338 ma
 Preflight gauge pressure (N_2): 3.8×10^{-5} torr
 Magnetic field strength: 2680 gauss

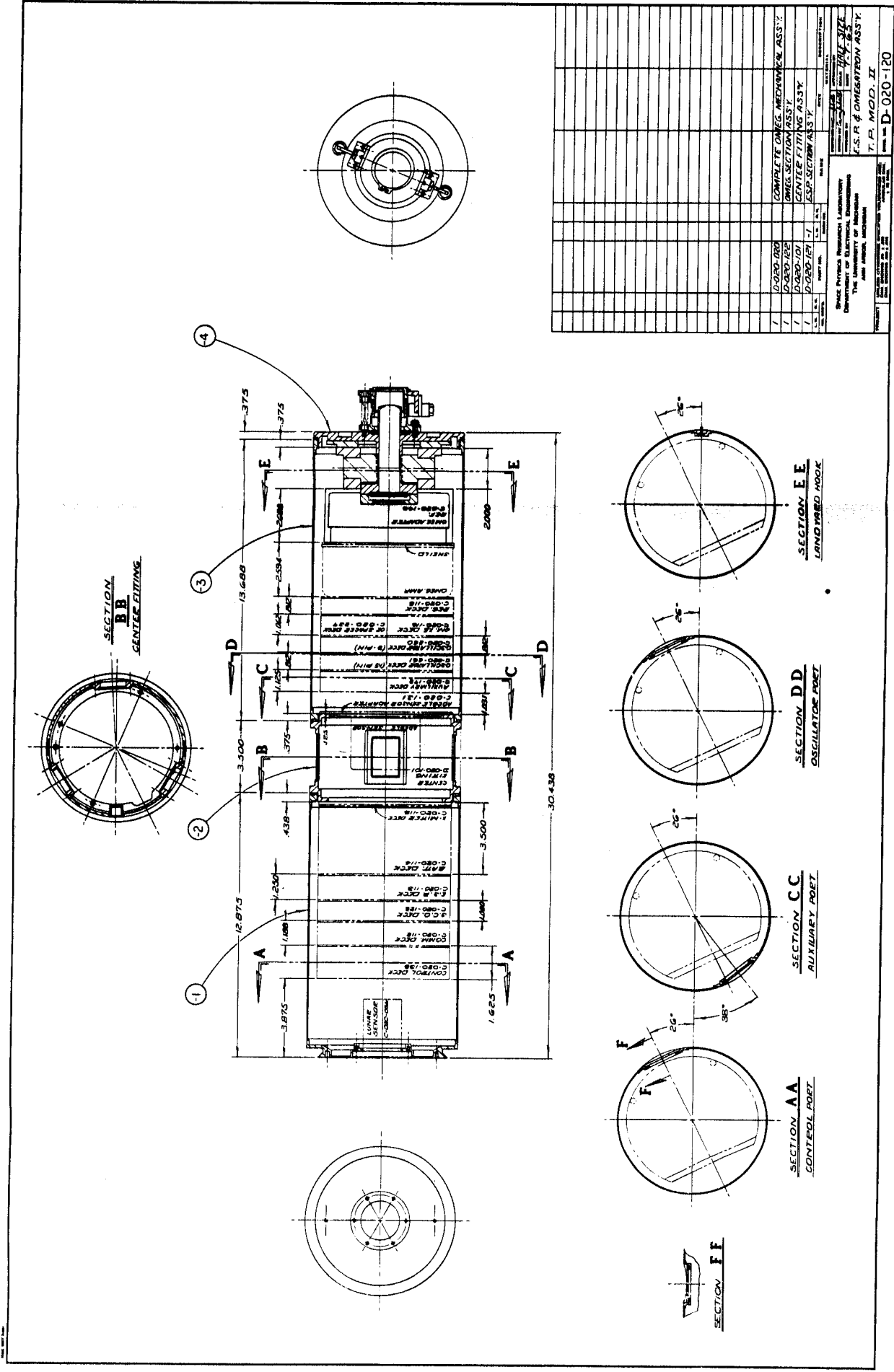
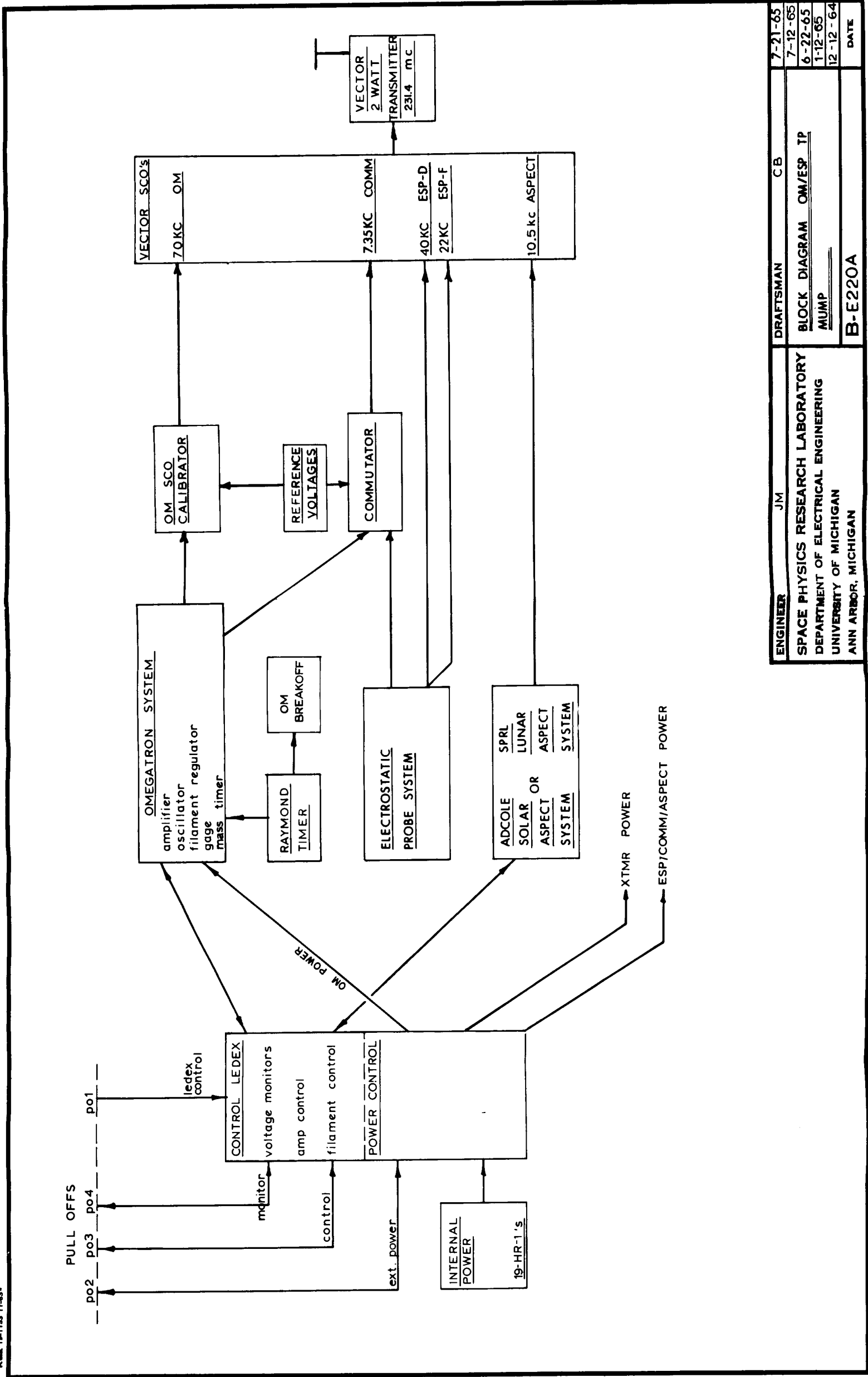


Figure 8. Thermosphere probe assembly.



ENGINEER	JM	DRAFTSMAN	CB	7-21-65
SPACE PHYSICS RESEARCH LABORATORY				7-12-65
DEPARTMENT OF ELECTRICAL ENGINEERING				6-22-65
UNIVERSITY OF MICHIGAN				1-12-65
ANN ARBOR, MICHIGAN				12-12-64
B-E220A				DATE

Figure 9. Block diagram (lunar and solar).

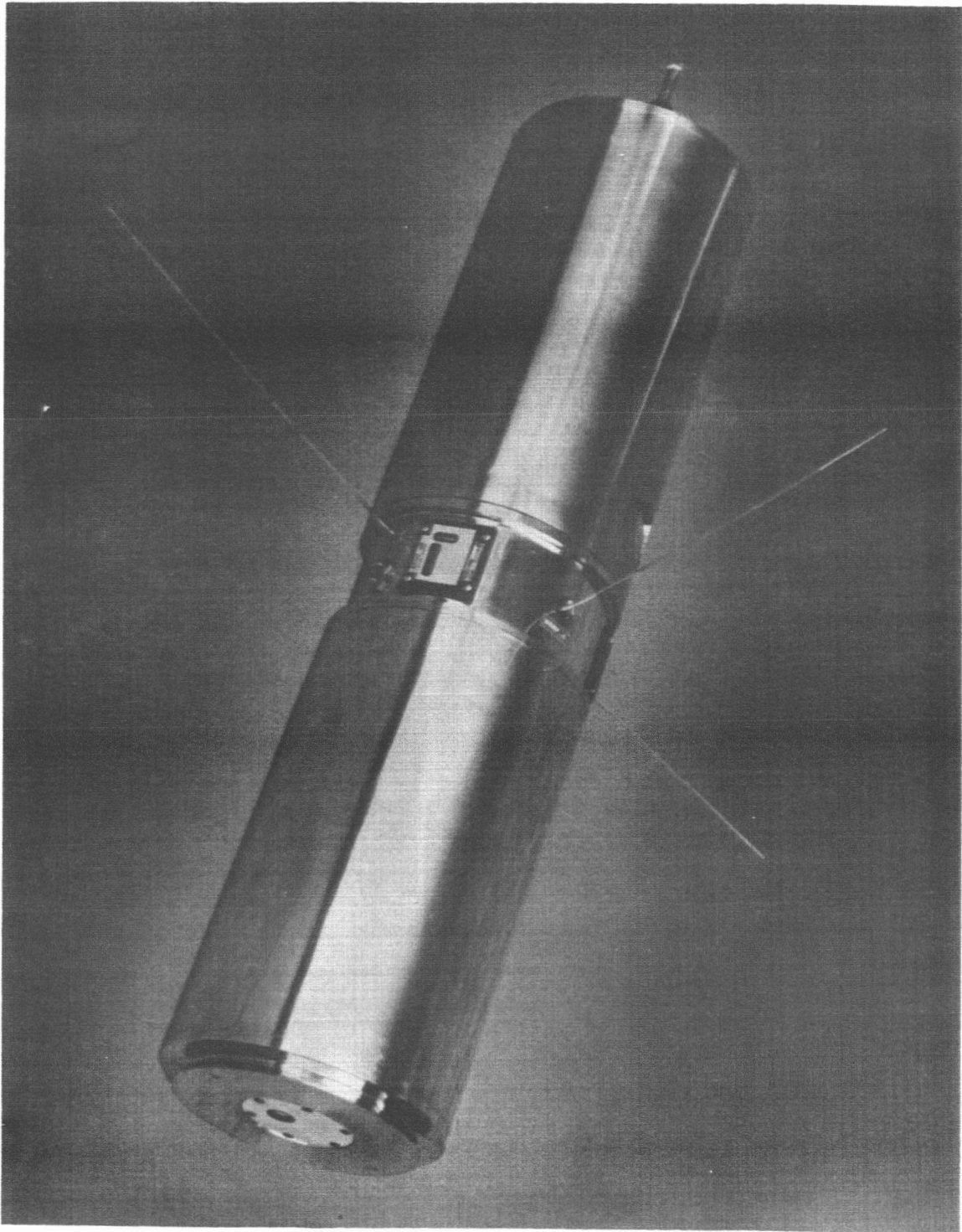


Figure 10. Assembled thermosphere probe.

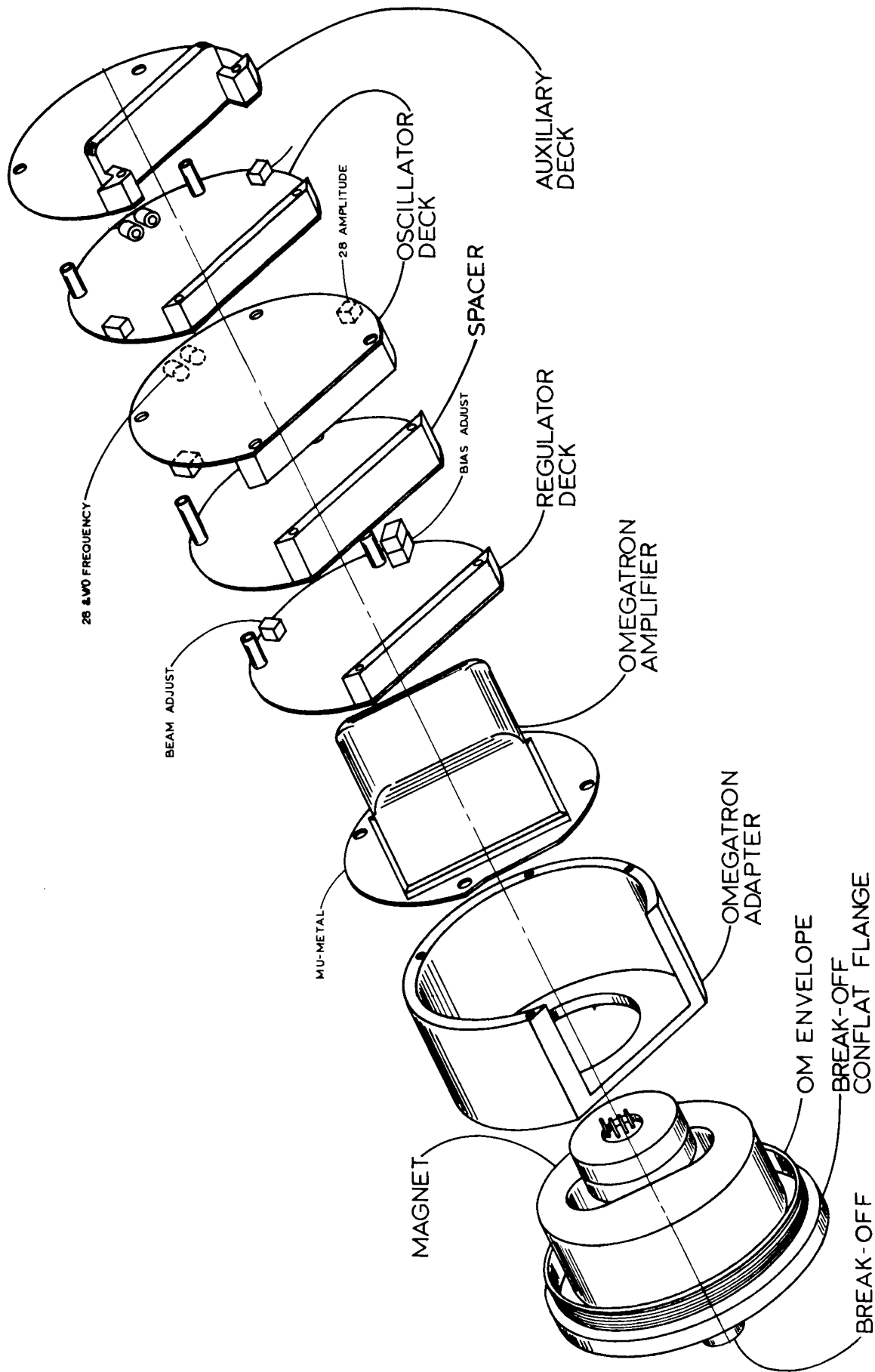
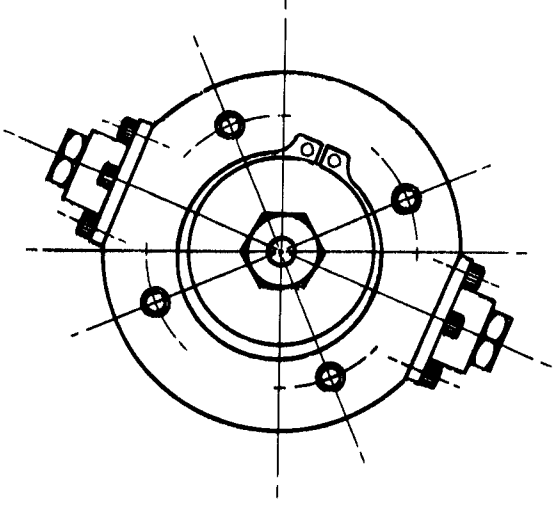


Figure 11. Omegatron expanded view.

-.062 APPROX. LOC. OF
16 EQ. SPACED SPOT WELDS

1. MACHINE C-020-074 -BREAK-OFF BASE WITHOUT CONFLAT GROOVE.
2. MACHINE C-020-077 -BREAK-OFF HAT & HELI-ARC WELD MODIFIED CRAWFORD SWAGELOK #200-1-4W-316 TO HAT. LEAK CHECK HELI-ARC WELD - MUST BE VACUUM TIGHT.
3. SEND DETAILS C-020-074 & C-020-077 TO COORS PORCELIN CO. TO BRAZE COORS' BREAK-OFF CERAMIC SEAL RING TO DETAILS C-020-074 & C-020-077.
4. SPOT WELD A-020-075 -BREAK-OFF GUARD TO C-020-077 -BREAK-OFF HAT AT U. OF M. AFTER BRAZING OF CERAMIC SEAL.
5. LEAK CHECK COMPLETE UNIT.
6. FINAL MACHINING OF CONFLAT GROOVE ON C-020-074 -BREAK-OFF BASE.



PROJECT				UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: DIM. FINISHES .001" & .002" DIAL FINISHES .001" & .002"			
SPACE PHYSICS RESEARCH LABORATORY DEPARTMENT OF ELECTRICAL ENGINEERING THE UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN				DRAWING NO. 1-200 DATE: 1-20-50			
L.N.	R. H.	PART NO.	NAME	QTY.	UNIT	PRICE	TOTAL
1	1	A-020-075	BREAK-OFF GUARD	1	EA.	1.00	1.00
1	1	C-020-074	BREAK-OFF BASE	1	EA.	1.00	1.00
4	1	A-020-079	OMEGATRON BREAK-OFF	4	EA.	1.00	4.00
1	1	C-020-077	BREAK-OFF HAT	1	EA.	1.00	1.00
1	1	C-020-078	BREAK-OFF ACTUATOR	1	EA.	1.00	1.00
1	1	A-020-075	BREAK-OFF GUARD	1	EA.	1.00	1.00
1	1	C-020-074	BREAK-OFF BASE	1	EA.	1.00	1.00
4	1	A-020-079	OMEGATRON BREAK-OFF	4	EA.	1.00	4.00
1	1	C-020-077	BREAK-OFF HAT	1	EA.	1.00	1.00
1	1	C-020-078	BREAK-OFF ACTUATOR	1	EA.	1.00	1.00

45

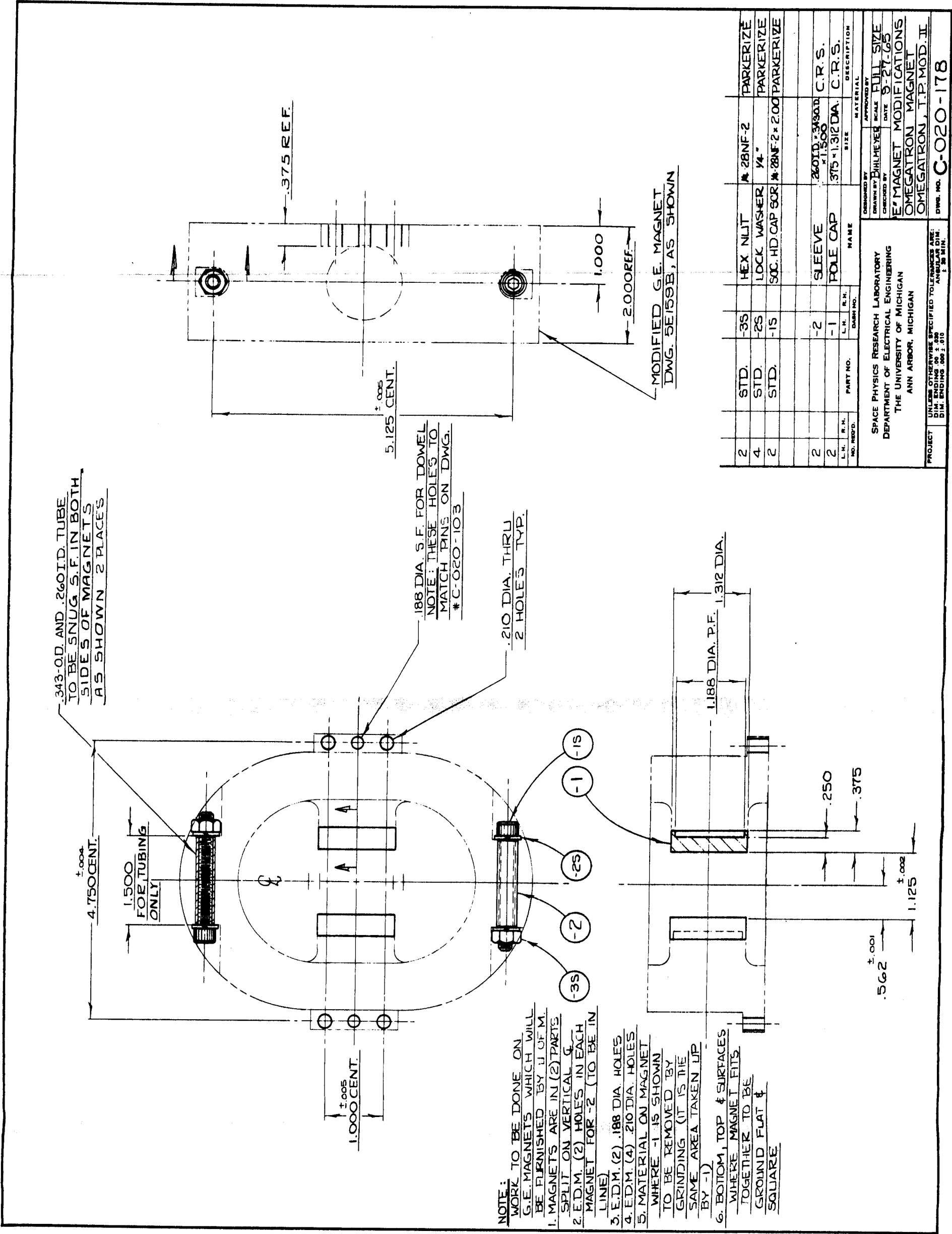


Figure 14. Omegatron magnet assembly.

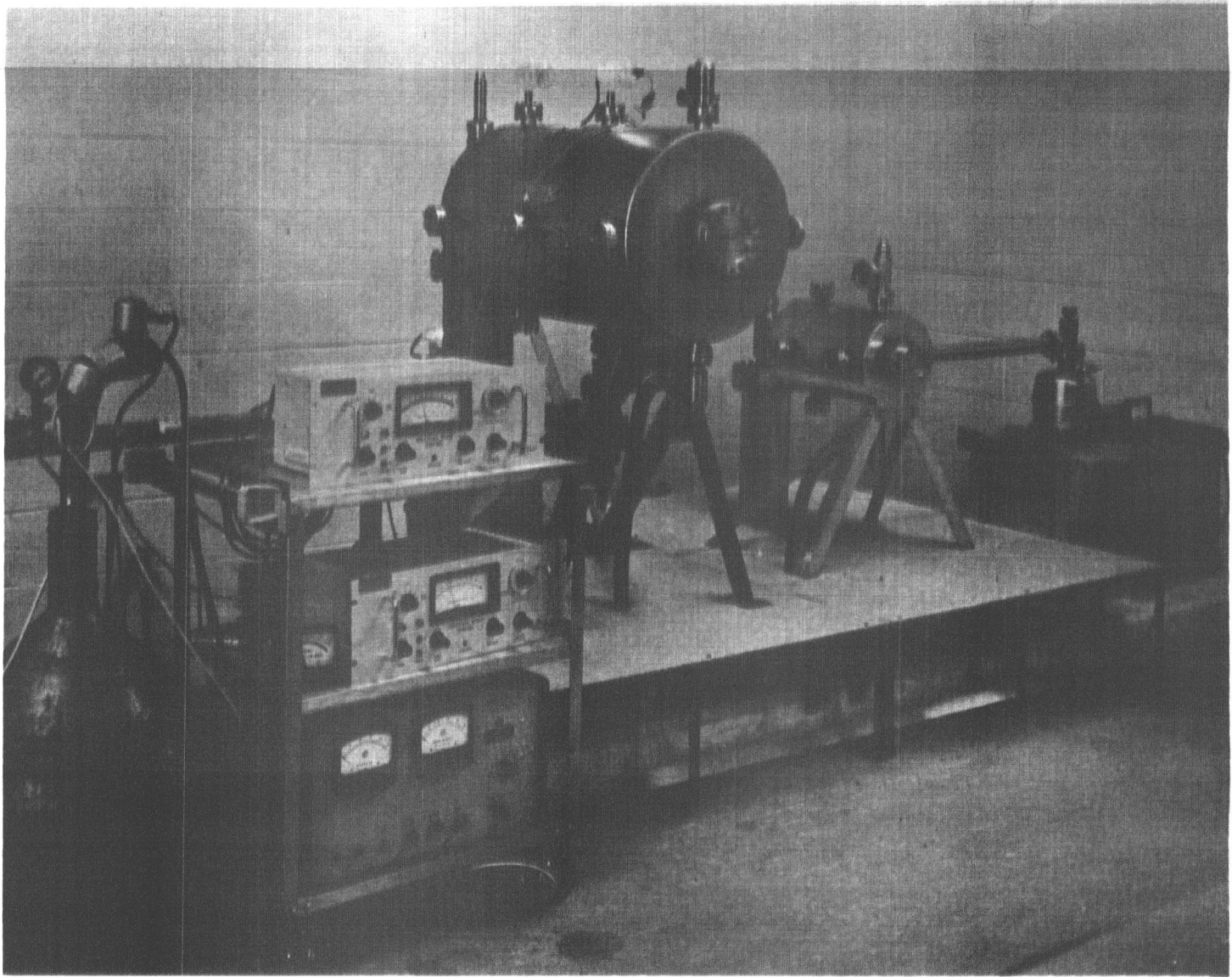
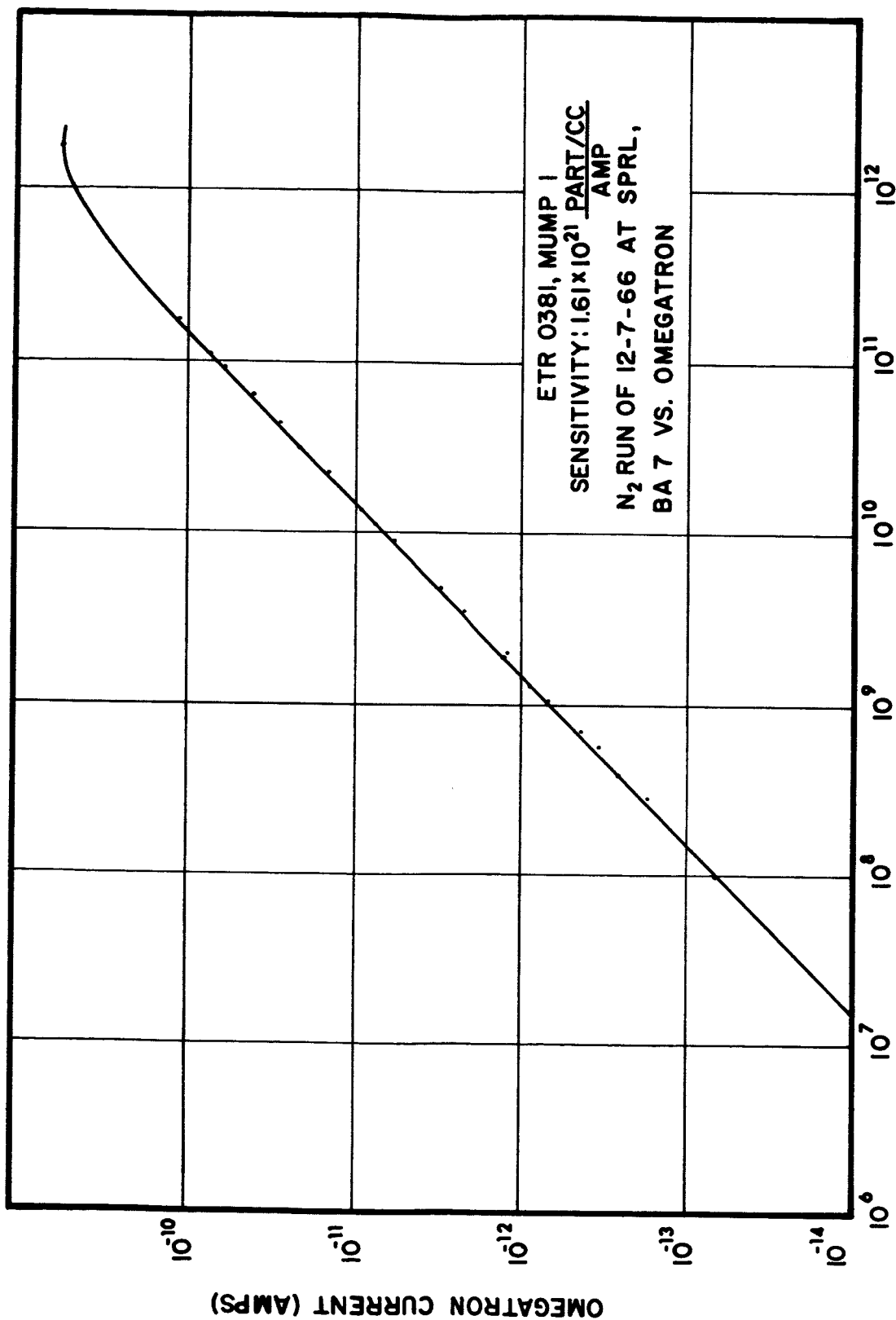


Figure 15. Calibration system.



NUMBER DENSITY (PART/CC)

3-30-67

Figure 16. Omegatron calibration of MUMP 1.

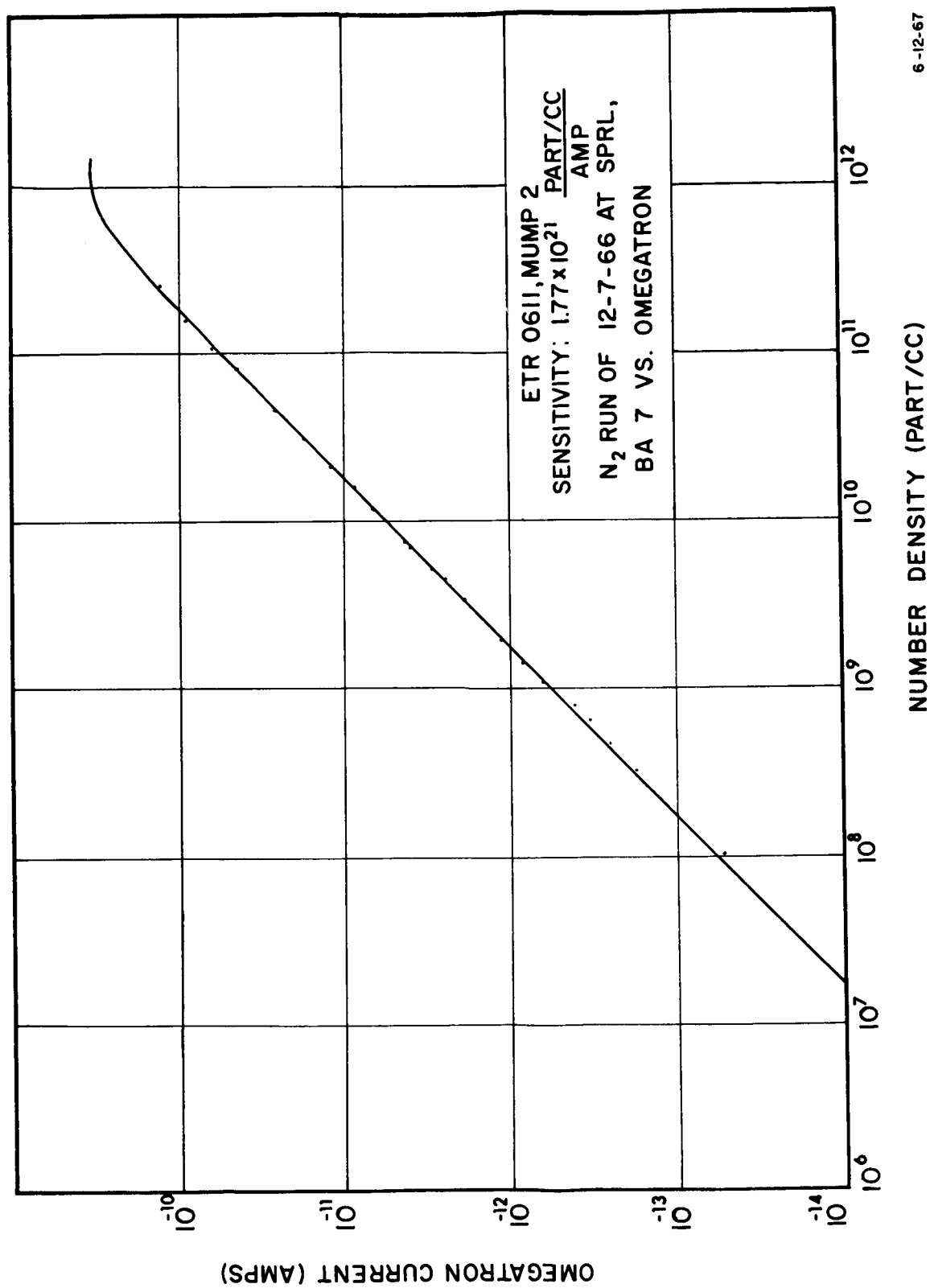


Figure 17. Omegatron calibration of MUMP 2.

6-12-67

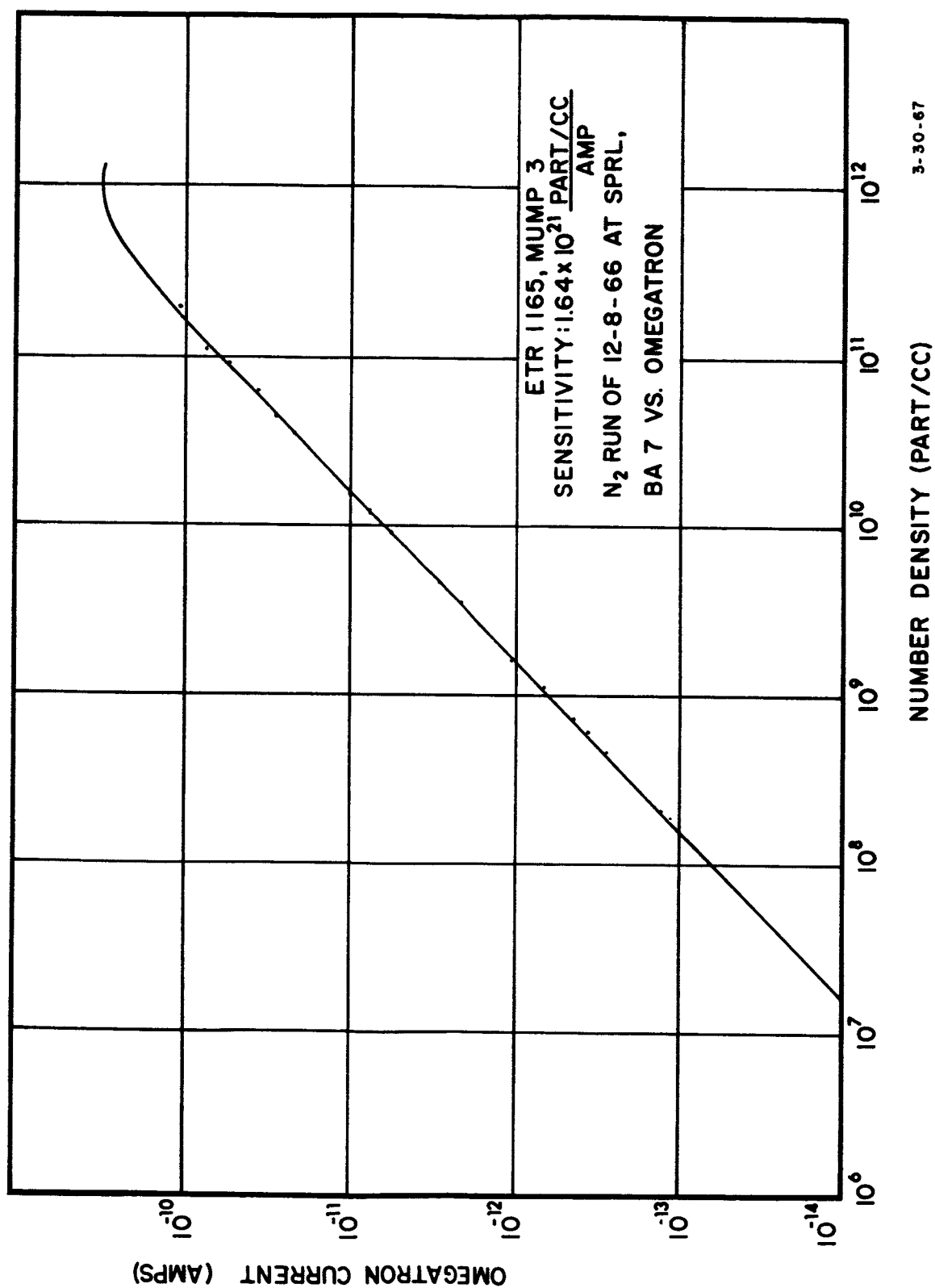


Figure 18. Omegatron calibration of MUMP 3.

3-30-67

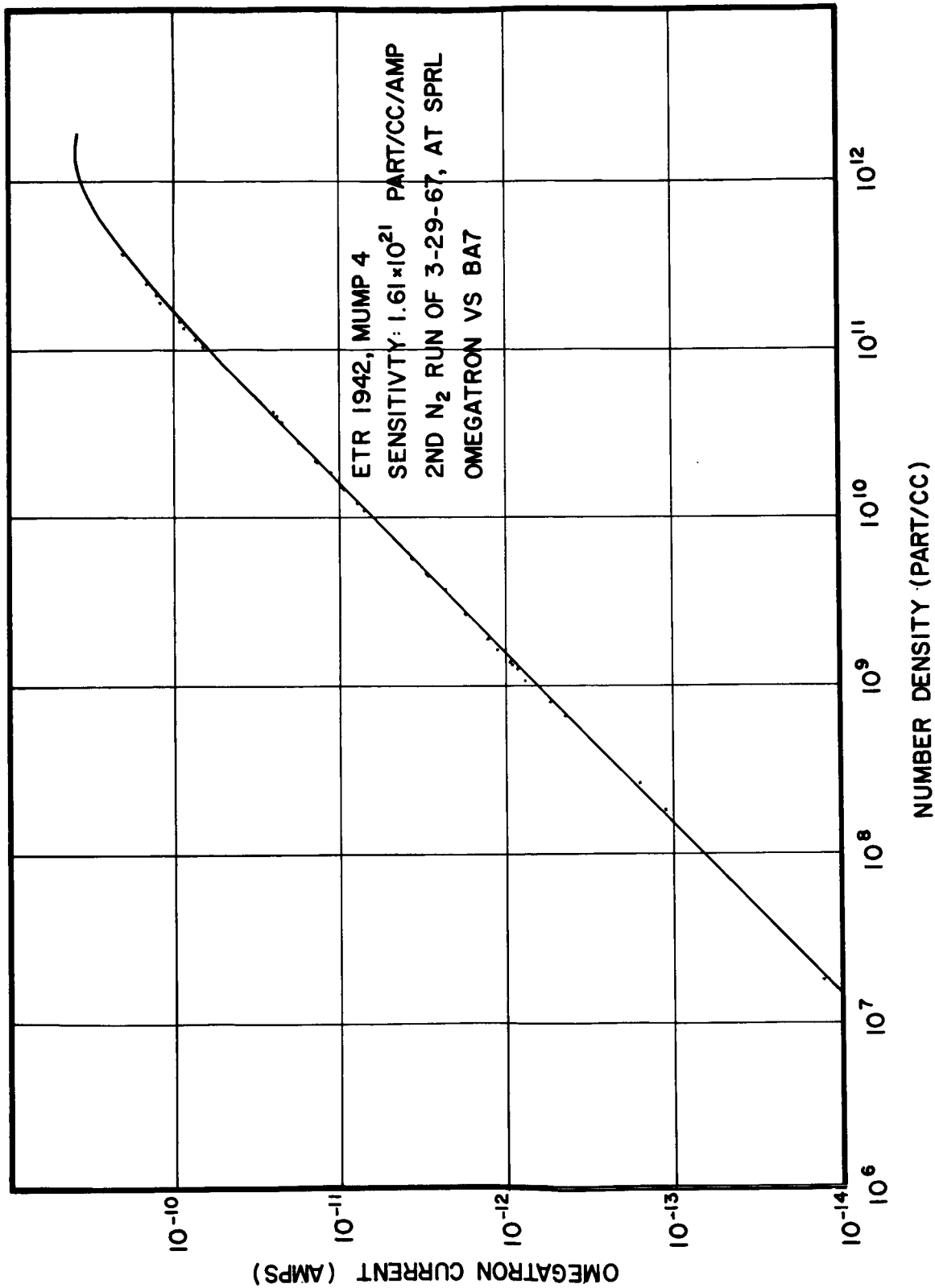


Figure 19. Omeatron calibration of MUMP 4.

6-2-67

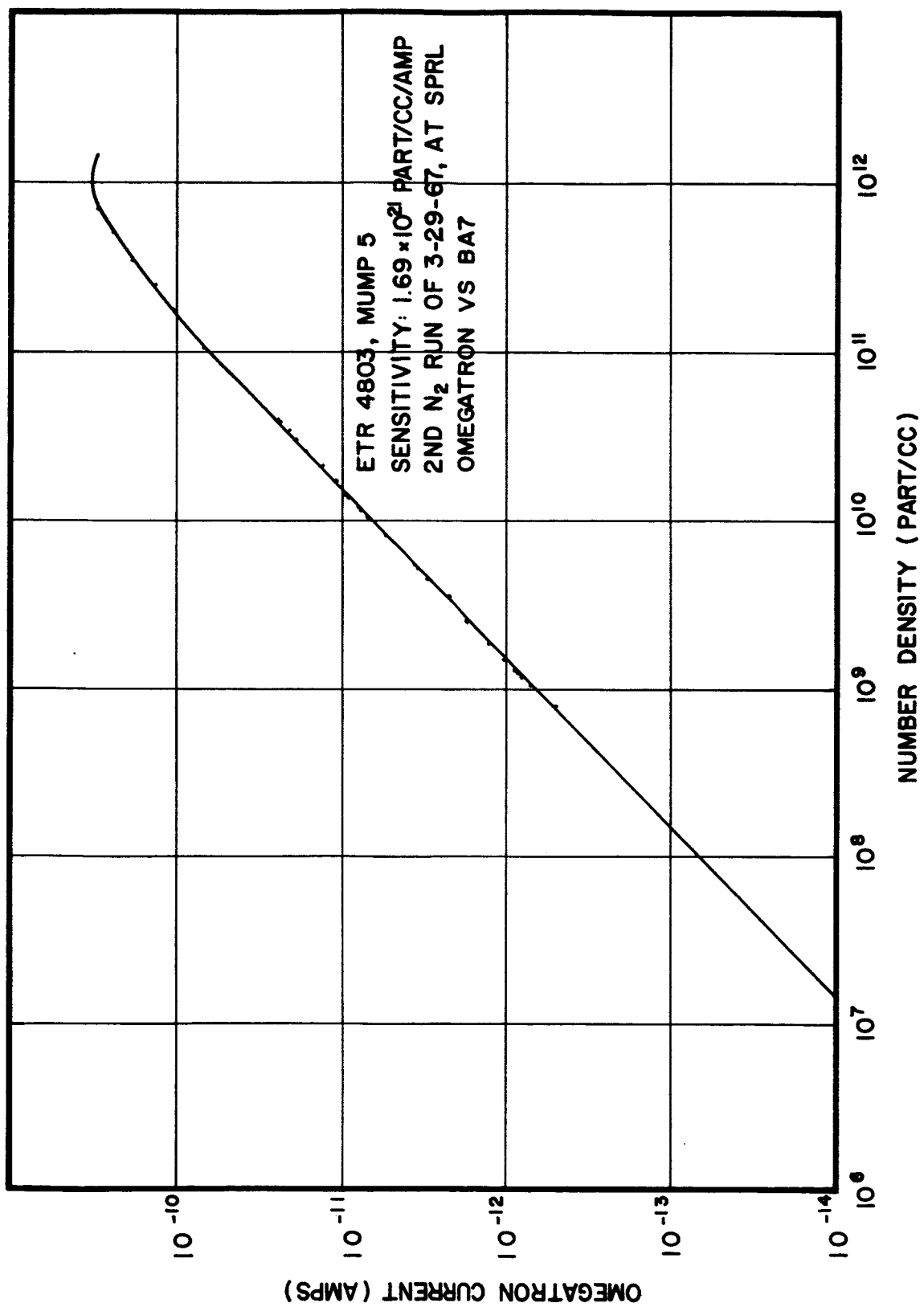


Figure 20. Omeatron calibration of MUMP 5.

6-2-67

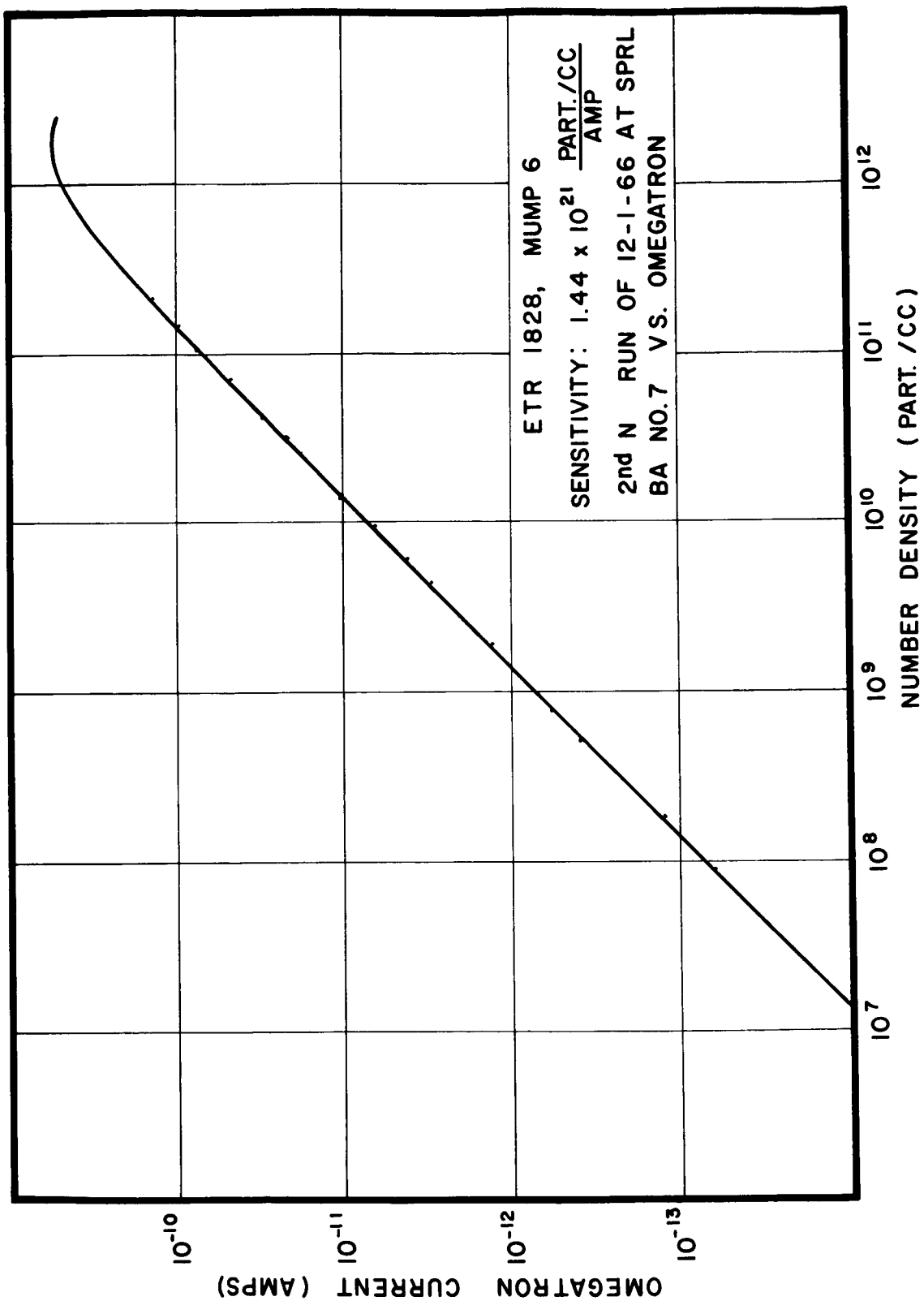


Figure 21. Omeatron calibration of MUMP 6.

3-31-67

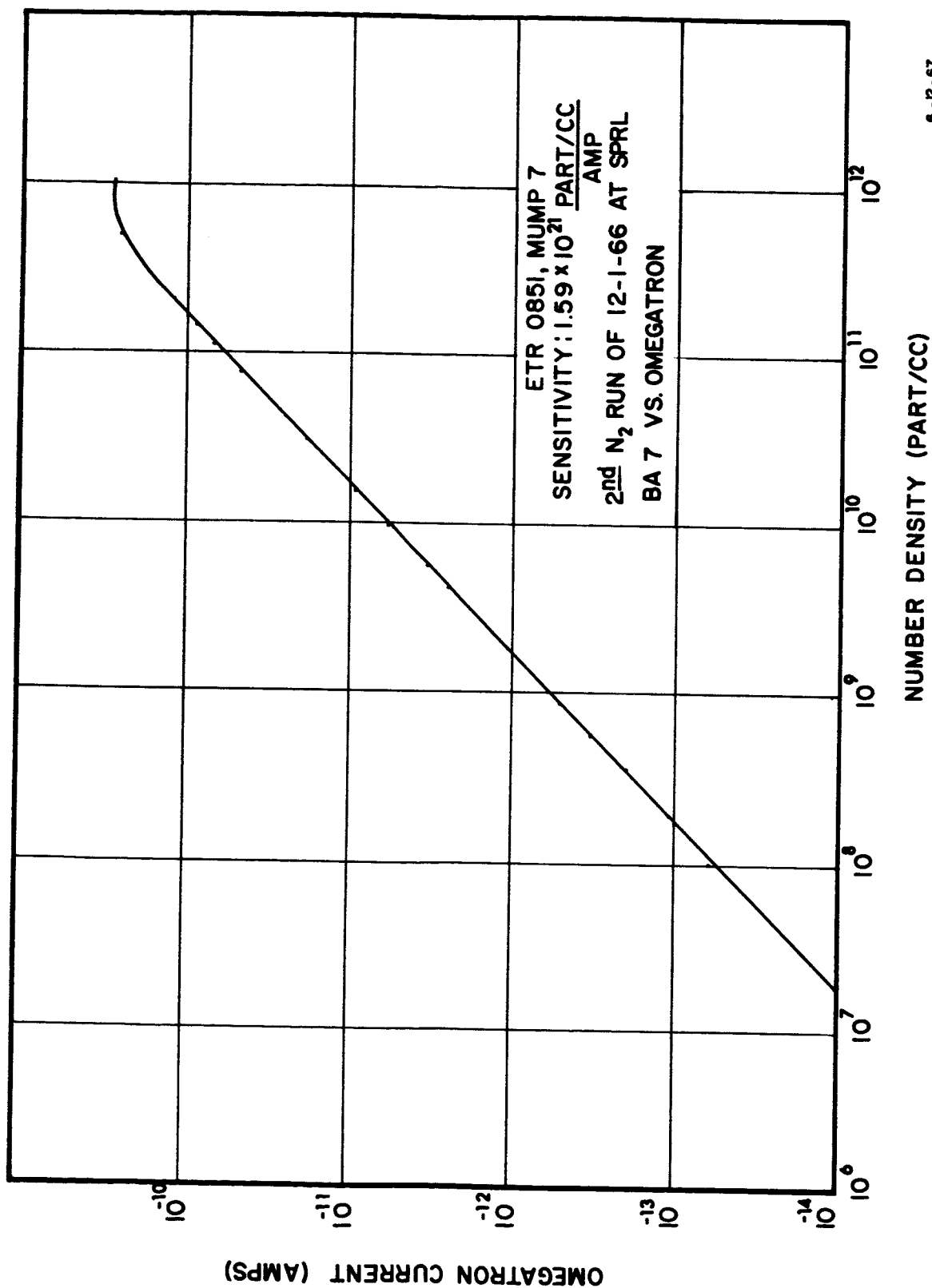
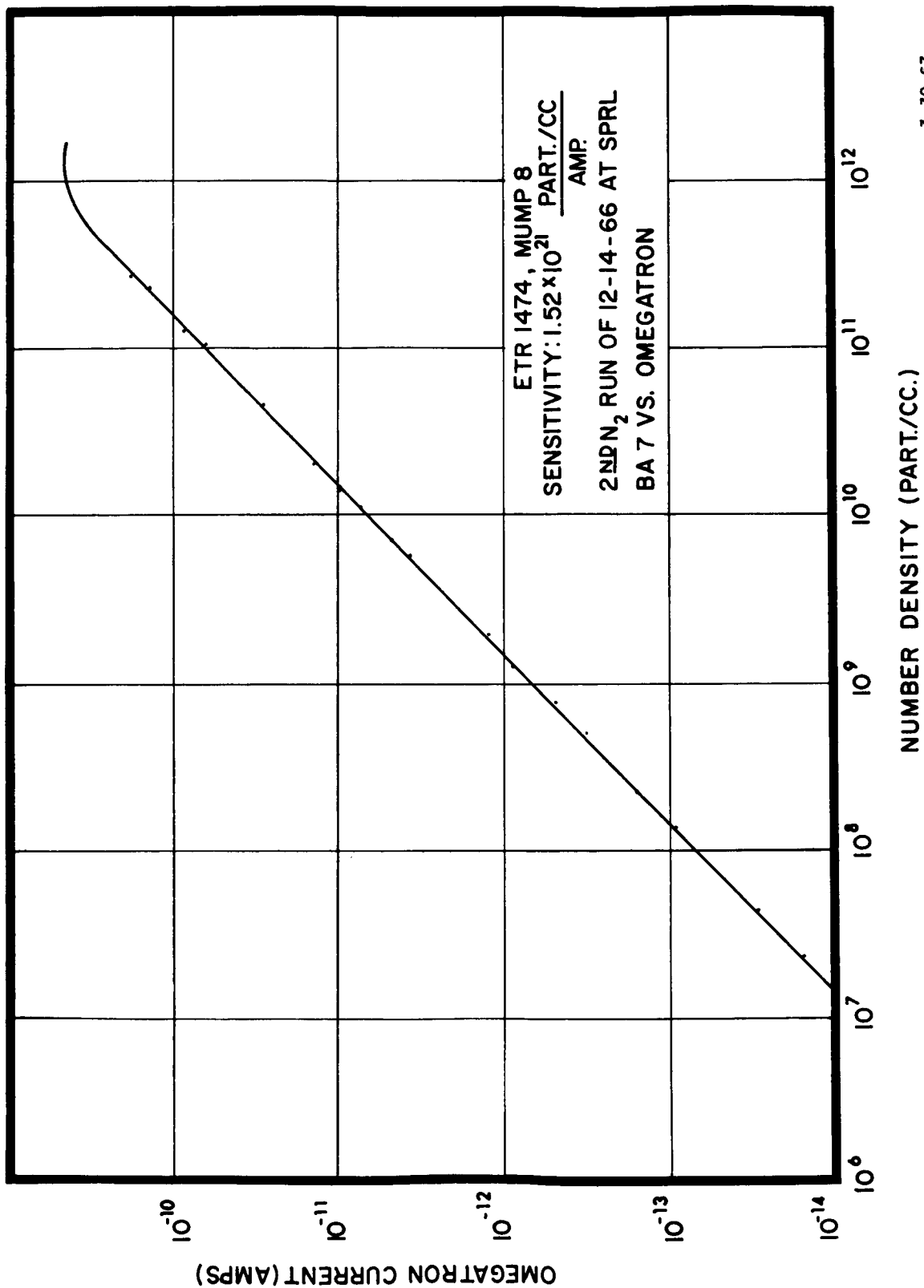


Figure 22. Omeatron calibration of MUMP 7.

6-2-67



3-30-67

Figure 23. Omeatron calibration of MUMP 8.

6.2 ELECTROSTATIC PROBE (ESP)

The electrostatic probe (ESP) system described consists of a cylindrical Langmuir probe, shown in Figure 24, which is immersed in the plasma, and an electronics unit which measures the current collected by the probe.

The electronics unit consists of a dc-dc converter, a ramp voltage generator, a three-range current detector, range switching relays, and associated logic circuitry. The electronics unit has two output channels, a data channel, and a computer channel. The data channel output is a voltage proportional to the collected probe current. The computer channel contains information on detector ranges, system calibration, and ramp voltage levels which allows data reduction by computer methods. System timing and the computer channel format are given in Figure 25.

The following are the specifications of the ESP system for Mump 1 through 8:

(1) , Input Power

1.54 watts at 28 volts

(2) Sensitivity

Mumps 1, 2, 3, 5

Mumps 4, 6, 7, 8

Range 1

20 μ a Full Scale*

10 μ a Full Scale

Range 2

2.0 μ a Full Scale

1.0 μ a Full Scale

Range 3

0.2 μ a Full Scale

0.1 μ a Full Scale

*Full scale output is defined as the +4.0 v from the 0.5 v output bias level.

(3) Ramp Voltage (ΔV)

Magnitude

Slope

High ΔV

-3 v TO +5 v

80 v/sec

Low ΔV

-1 v TO +1.8 v

28 v/sec

(4) Output

Voltage

-0.6 v TO +5.6 v

Resistance

less than 2 K

Bias Level

+0.5 v

(5) Calibration

ON-FOR 600 msec

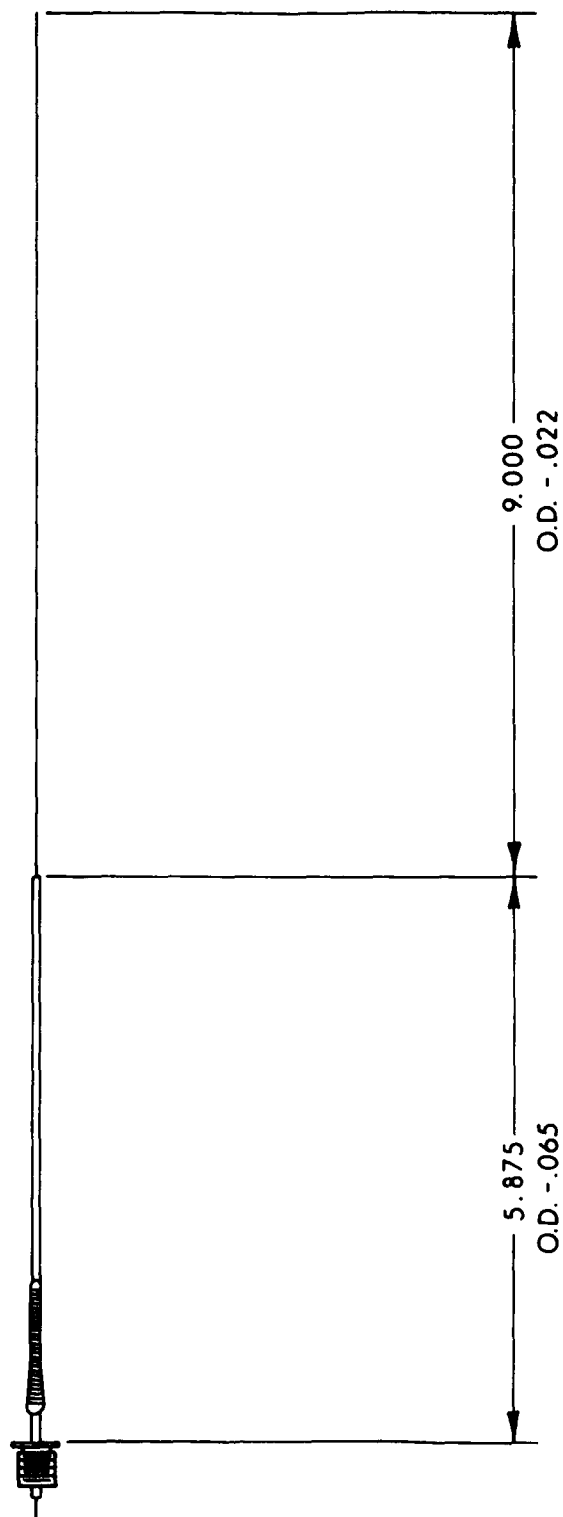
Interval 28.8 sec

Synchronized with ΔV

(6) Timing (see Figure 25)

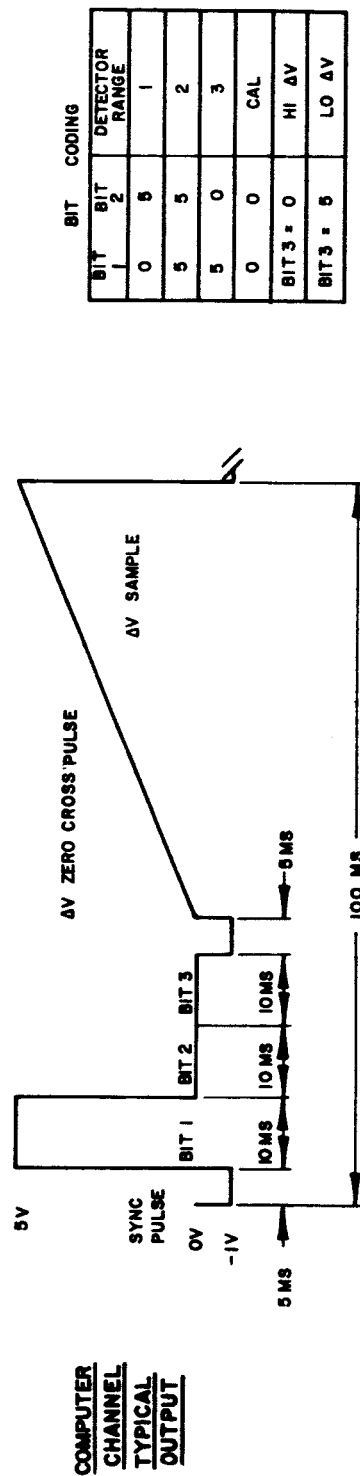
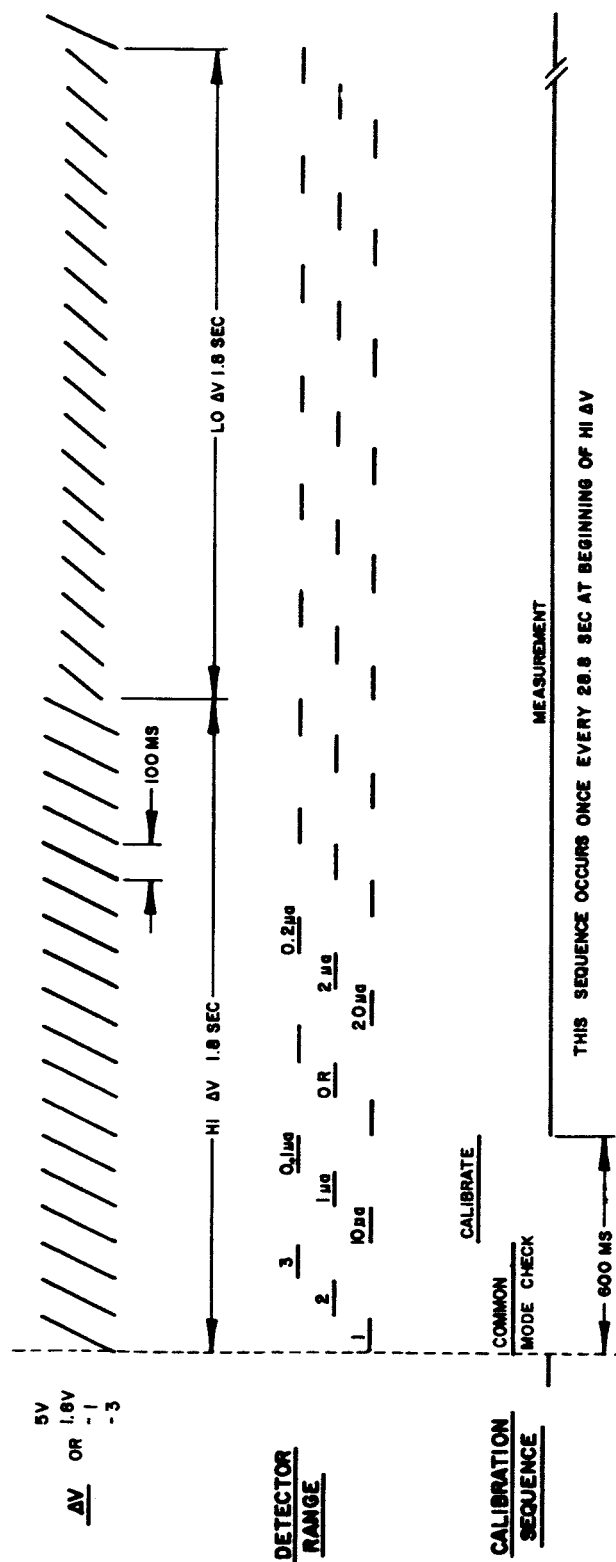
ΔV -High-Low alternated every 1.8 sec

Range - Sequential, 100 msec each range



ELECTROSTATIC PROBE

Figure 24. Electrostatic probe dimensions.



MUMP SYSTEM TIMING & COMPUTER CHANNEL FORMAT

Figure 25. Electrostatic probe timing and computer channel format.

6.3 SUPPORT MEASUREMENT AND INSTRUMENTATION

6.3.1 Aspect Determination System

The aspect determination systems, utilized for the eight payloads described herein, were identical to those used on previous Thermosphere Probe payloads. The launches performed during the sunlit hours utilized the Adcole Corporation solar sensors with their shift register electronics package. The launches performed at night utilized the University of Michigan lunar sensor. Adequate information for the determination of payload aspect was received in all cases. However, one of the solar aspect sensors malfunctioned after operating properly for a short period during the initial part of the flight. Details of the malfunction are discussed in Section 7.

In all cases the data were analyzed by a technique which used the velocity vector as a reference (Taeusch, Carignan, Niemann, and Nagy, 1965). It was hoped that the Adcole Corporation earth sensors used for the sunlit flights would yield enough information to allow aspect solutions independent of the velocity vector technique. Such information would permit a study of atmospheric winds. However, the earth sensors did not provide adequately accurate data and will subsequently not be used in the future. Other techniques are being attempted to recover the atmospheric wind data. If the techniques are successful, the results will be reported in the future.

The minimum angles of attack versus flight time for each flight are given in Figures 26 through 33. These angles are believed accurate to better than $\pm 5^\circ$.

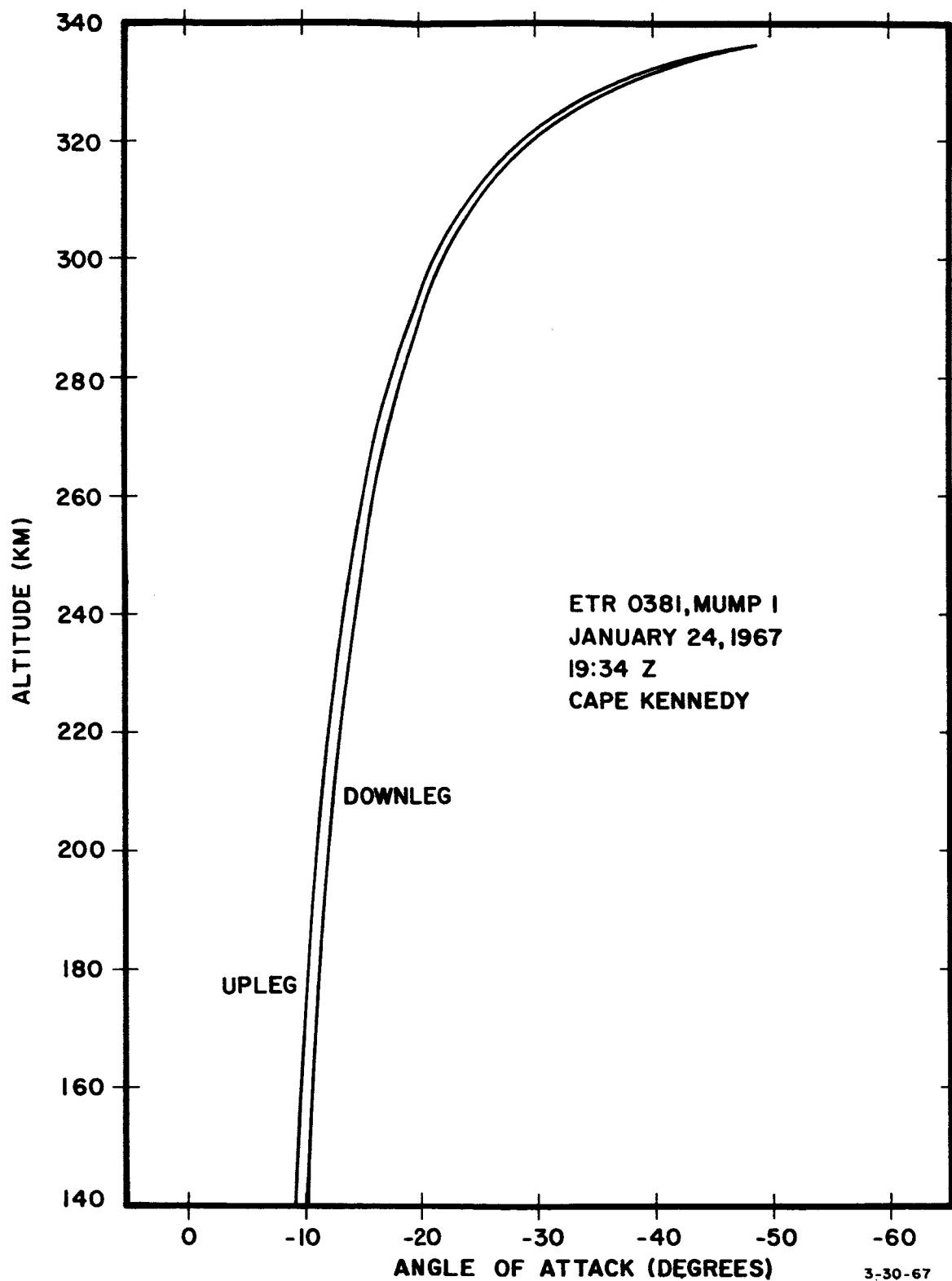
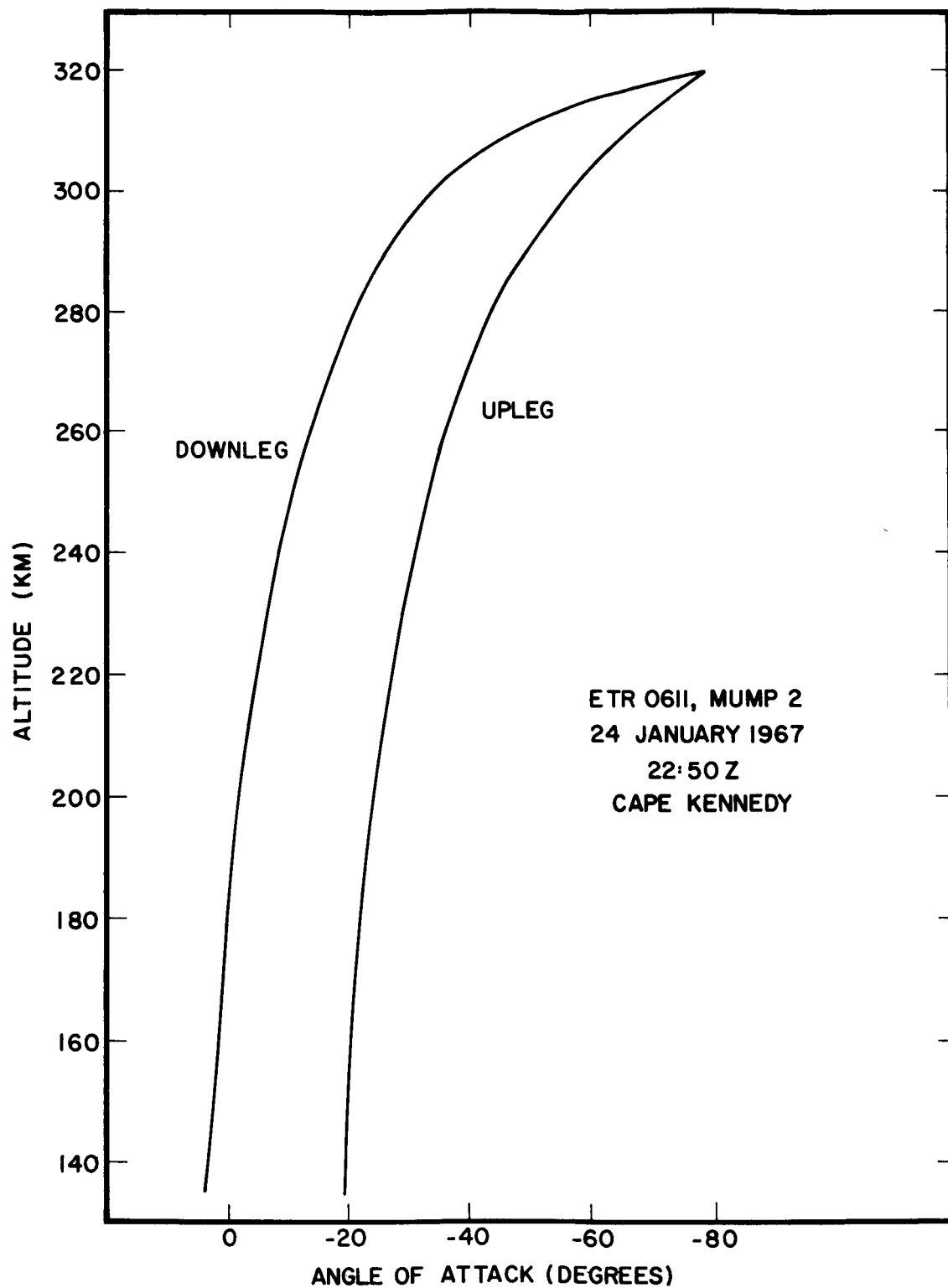


Figure 26. Minimum angle of attack vs. altitude for MUMP 1.



6-12-67

Figure 27. Minimum angle of attack vs. altitude for MUMP 2.

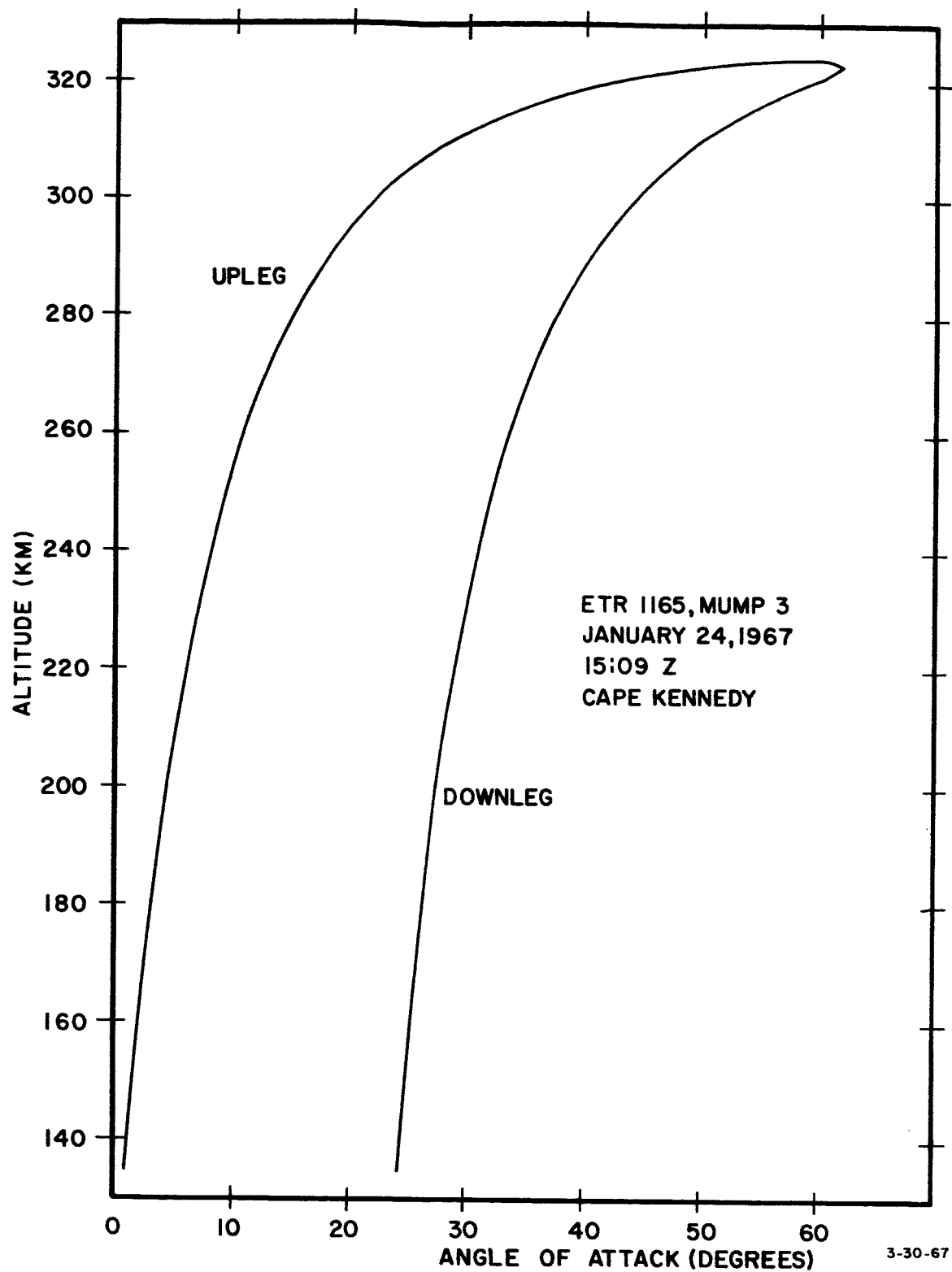
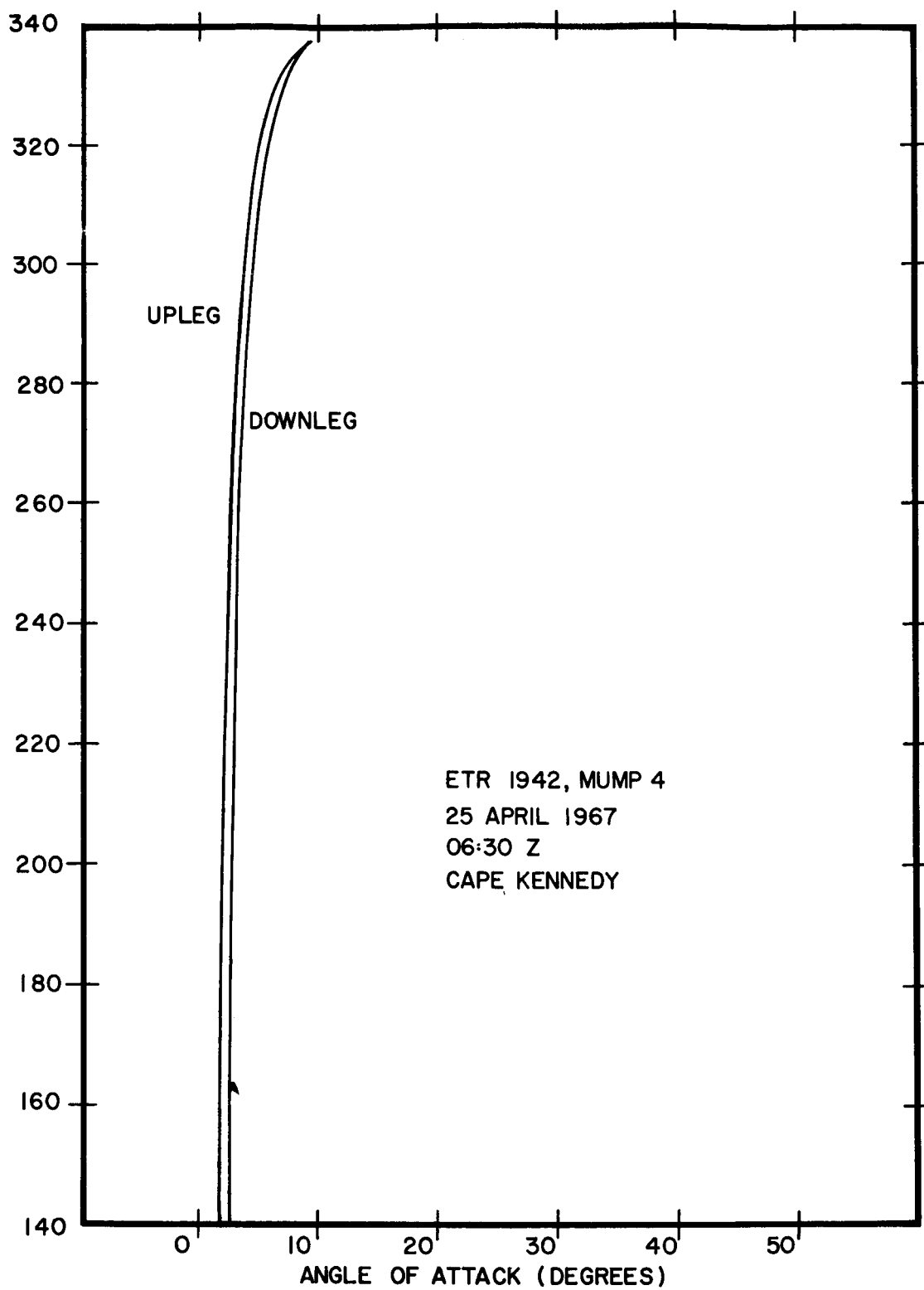
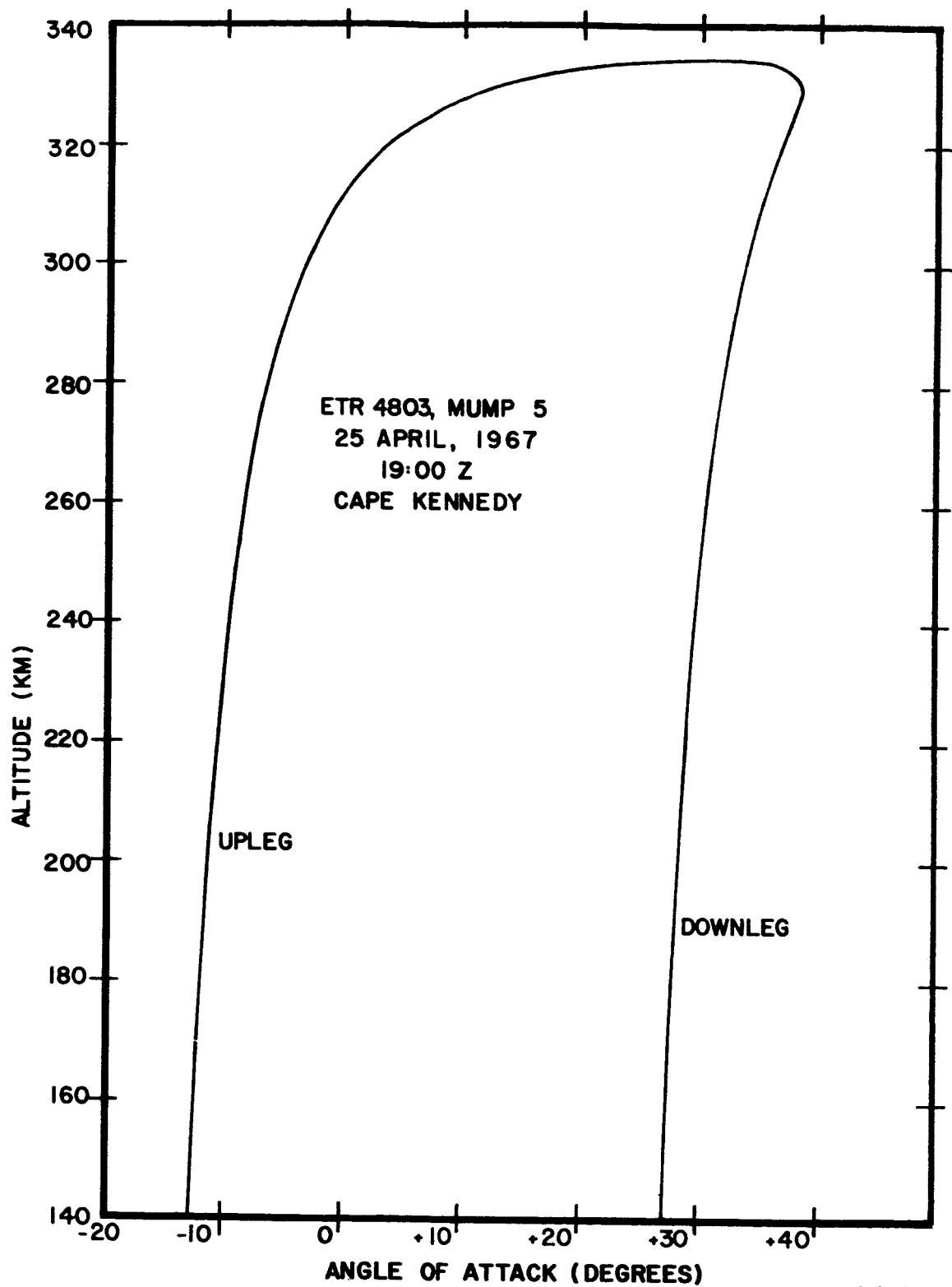


Figure 28. Minimum angle of attack vs. altitude for MUMP 3.



6-2-67

Figure 29. Minimum angle of attack vs. altitude for MUMP 4.



6-2-67

Figure 30. Minimum angle of attack vs. altitude for MUMP 5.

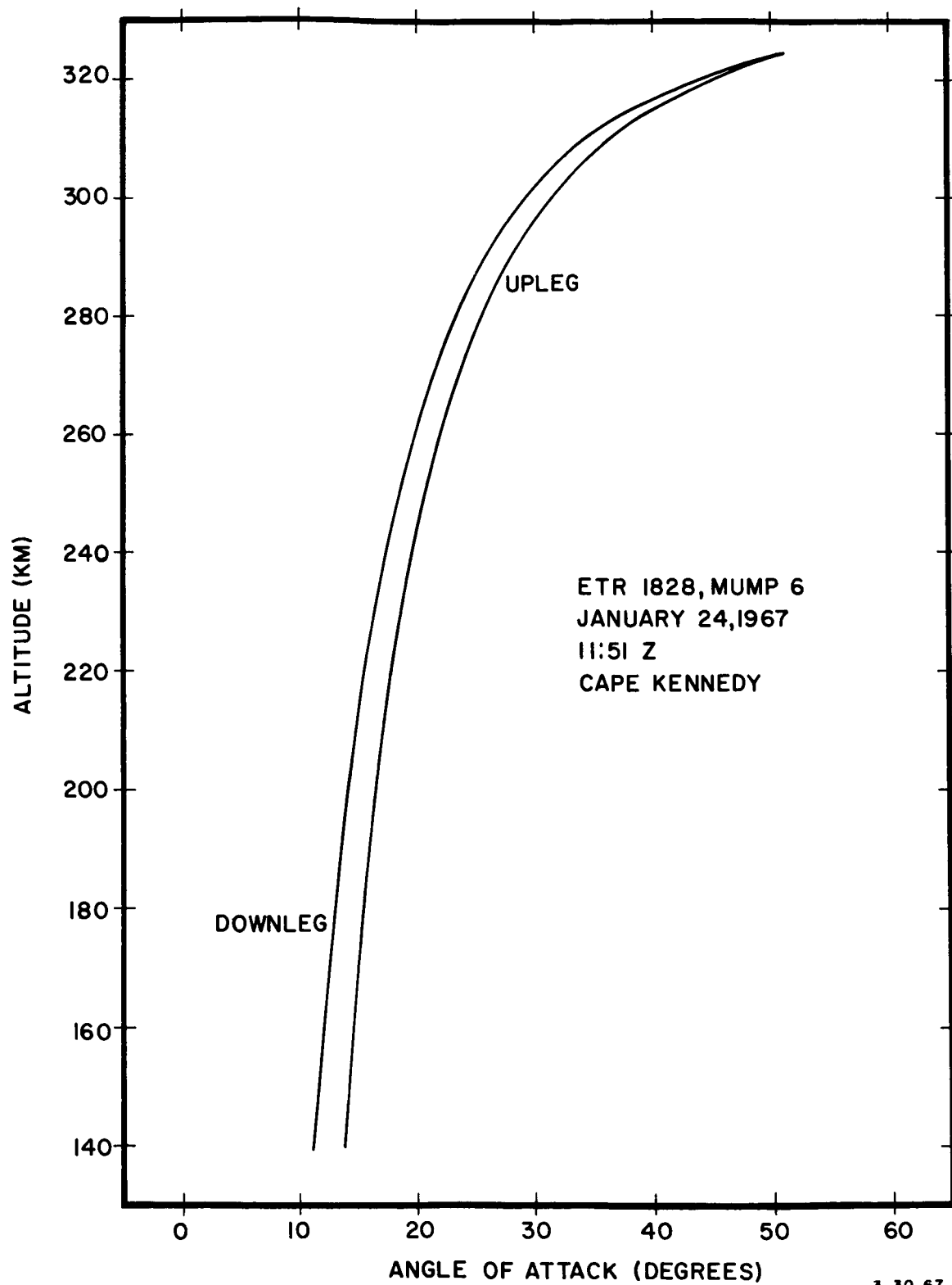
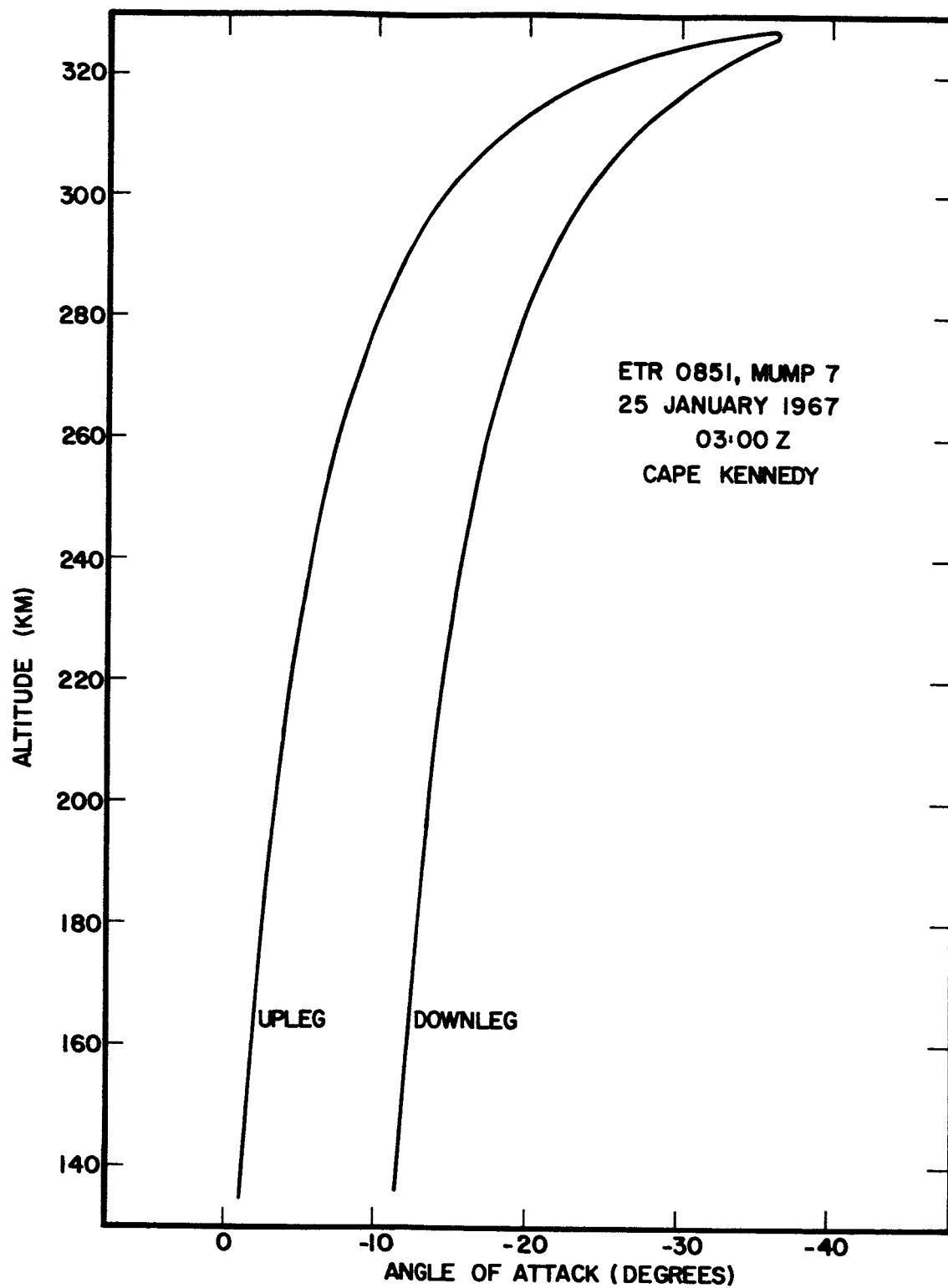


Figure 31. Minimum angle of attack vs. altitude for MUMP 6.



6-12-67

Figure 32. Minimum angle of attack vs. altitude for MUMP 7.

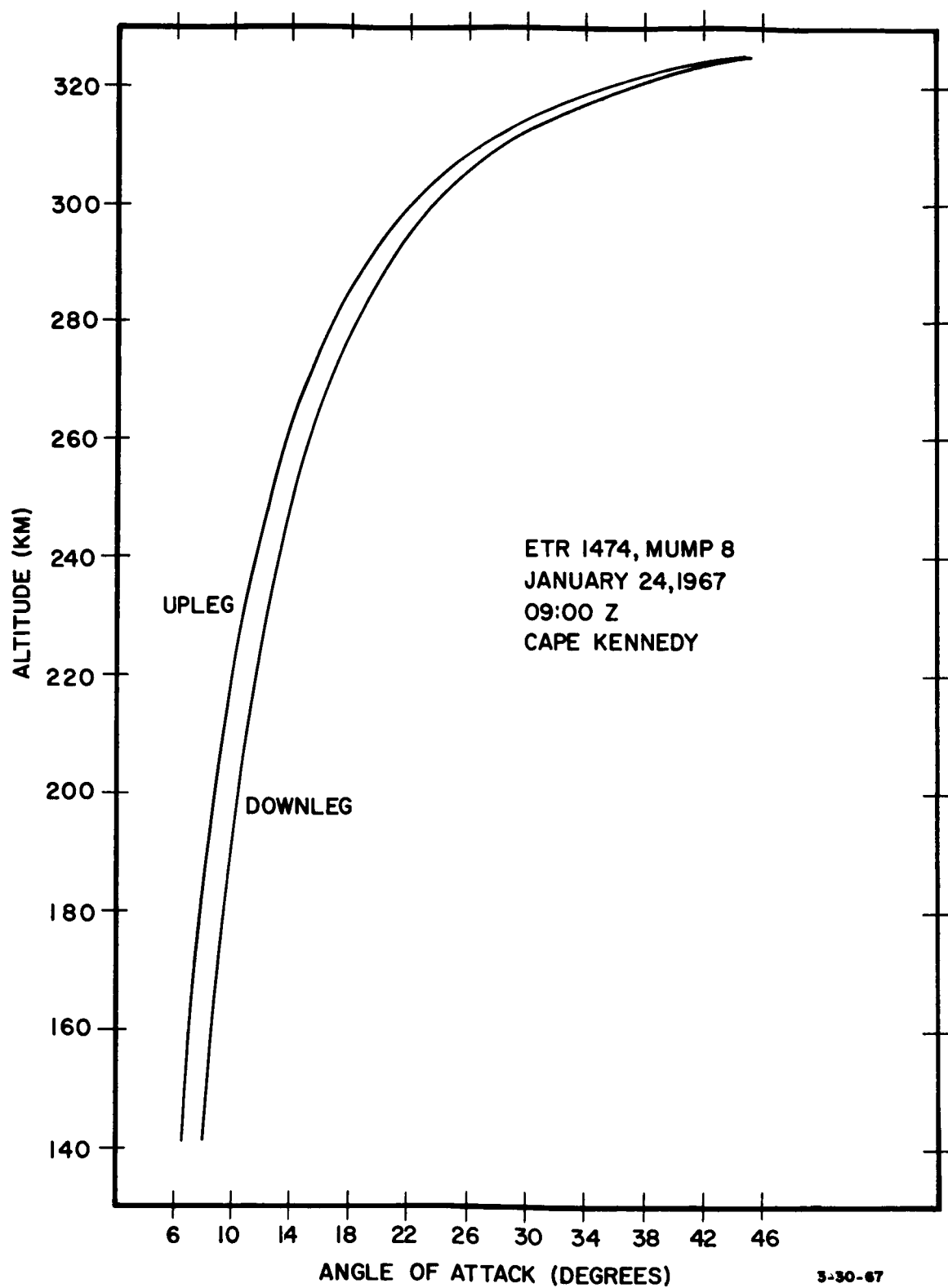


Figure 33. Minimum angle of attack vs. altitude for MUMP 8.

6.3.2 Telemetry

The payload data were transmitted in real time by PAM/FM/FM telemetry systems at 231.4 MHz with a nominal output of 2.5 watts. The system used subcarrier channels assigned as outlined on the following pages.

ETR 0381

MUMP 1

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	3113-25	70 kHz	1050 Hz	Omegatron
16	2499-25	40 kHz	600 Hz	ESP-Data
14	2497-25	22 kHz	330 Hz	ESP-Flag
12	2482-25	10.5 kHz	160 Hz	Aspect
11	2480-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	TRPT-250	Serial Number:	2839
	Power Amplifier:	Type TRFP-2V-1	Serial Number:	521
	Mixer Amplifier:	Type TA58A	Serial Number:	1063

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 0611

MUMP 2

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	2503-25	70 kHz	1050 Hz	Omegatron
16	2498-25	40 kHz	600 Hz	ESP-Data
14	2495-25	22 kHz	330 Hz	ESP-Flag
12	3102-25	10.5 kHz	160 Hz	Aspect
11	2478-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	TRPT-250	Serial Number:	2846
	Power Amplifier:	Type TRFP-2V-1	Serial Number:	522
	Mixer Amplifier:	Type TA58A	Serial Number:	1066

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 1165

MUMP 3

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	3111-25	70 kHz	1050 Hz	Omegatron
16	2542-25	40 kHz	600 Hz	ESP-Data
14	2493-25	22 kHz	330 Hz	ESP-Flag
12	2487-25	10.5 kHz	160 Hz	Aspect
11	2476-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number: 2845
	Power Amplifier:	Type TRFP-2V-1	Serial Number: 523
	Mixer Amplifier:	Type TA58A	Serial Number: 1065

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 1942

MUMP 4

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	2506-25	70 kHz	1050 Hz	Omegatron
16	3108-25	40 kHz	600 Hz	ESP-Data
14	3107-25	22 kHz	330 Hz	ESP-Flag
12	1985-25	10.5 kHz	160 Hz	Aspect
11	3100-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number:	2844
	Power Amplifier:	Type TRFP-2V-1	Serial Number:	524
	Mixer Amplifier:	Type TA58A	Serial Number:	1123

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 4803

MUMP 5

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	2504-25	70 kHz	1050 Hz	Omegatron
16	2502-25	40 kHz	600 Hz	ESP-Data
14	2494-25	22 kHz	330 Hz	ESP-Flag
12	2483-25	10.5 kHz	160 Hz	Aspect
11	2477-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number:	2848
	Power Amplifier:	Type TRFP-2V-1	Serial Number:	525
	Mixer Amplifier:	Type TA58A	Serial Number:	1122

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 1828

MUMP 6

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	3112-25	70 kHz	1050 Hz	Omegatron
16	3109-25	40 kHz	600 Hz	ESP-Data
14	3106-25	22 kHz	300 Hz	ESP-Flag
12	3104-25	10.5 kHz	160 Hz	Aspect
11	3101-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number: 2490
	Power Amplifier:	Type TRFP-2V-1	Serial Number: 428
	Mixer Amplifier:	Type TA58A	Serial Number: 1124

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 0851

MUMP 7

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	2505-25	70 kHz	1050 Hz	Omegatron
16	3110-25	40 kHz	600 Hz	ESP-Data
14	3105-25	22 kHz	330 Hz	ESP-Flag
12	3103-25	10.5 kHz	160 Hz	Aspect
11	3099-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number:	2974
	Power Amplifier:	Type TRFP-2V-1	Serial Number:	535
	Mixer Amplifier:	Type TA58A	Serial Number:	1060

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

ETR 1474

MUMP 8

Subcarrier Channels (SCO-type TS58)

IRIG Band	Serial Number	Center Frequency	Nominal Frequency Response	Function
18	2560-25	70 kHz	1050 Hz	Omegatron
16	2010-25	40 kHz	600 Hz	ESP-Data
14	1891-25	22 kHz	330 Hz	ESP-Flag
12	1689-25	10.5 kHz	160 Hz	Aspect
11	1977-25	7.35 kHz	110 Hz	Commutator

Transmitter:	Driver:	Type TRPT-250	Serial Number	2973
	Power Amplifier:	Type TRFP-2V-1	Serial Number	536
	Mixer Amplifier:	Type TA58A	Serial Number	1057

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 27 volt output.

6.3.3 Housekeeping Monitors

Outputs from various monitors throughout the instrumentation provide information bearing on the operations of the electronic components during flight. These outputs are fed to a thirty-segment commutator which runs at one rps. The commutator assignments are as follows:

COMMUTATOR FORMAT FOR MUMP

SEG. NO.	SEGMENT ASSIGNMENT	EXPECTED READING
1	RANGE	4.9/8 0/1
2	OUT	4.95/OFF .83/CAL
3	FIL	3.1/ON .11/OFF
4	BEAM	3.2/ON .46/OFF
5	BIAS	3.95
6	RF	3.1/N ₂ 2.3/O ₂ 2.1/0
7	PRESS	1.8/OFF
8	TH-GAGE	3.8/20° 3.5/25° 3.1/30°
9	TH-AMP	" " "
10	TH-REG	" " "
11	TH-NO	" " "
12	TH-XTMR	" " "
13	OPEN	
14	OPEN	
15	28/5	E ₀ /E = 1/6.11 OR 4.5/27.5
16	POS	5.0/7 4.2/8 2.7/10 2.0/11
17	CAL V	5.0
18	TH-CM	3.8/20° 3.5/25° 3.1/30°
19	"	"
20	"	"
21	"	"
22	"	"
23	"	"
24	0 CAL	0.00
25	1 CAL	1.00
26	2 CAL	2.00
27	3 CAL	3.00
28	4 CAL	4.00
29 & 30	5 CAL	5.00 (FRAME SYNC)

7. ENGINEERING RESULTS

Because of the nature of program objectives, no engineering innovations of consequence were introduced into the instrumentation. Rather, every effort was made to use previously flight-tested designs. The three night shots were identical to the Thermosphere Probe launched by NASA 18.22, and the day shots differed only in their use of a solar aspect sensor and in the sensitivity of the Langmuir probe current detector.

A great deal of laboratory effort was devoted to an attempt to find a surface treatment for the omegatron gauge and envelope which would permit a measurement of atomic oxygen abundance. The results of the laboratory studies, insofar as permitting the atomic oxygen measurement to be made, were negative, and the measurement was reluctantly abandoned. The circuitry required for the measurement had already been incorporated into the instrument and was merely disabled. As a consequence, measurement of complete N_2 density profiles on both up and downleg was permitted.

The recovery of 100% data was realized from all eight shots. With two known exceptions all eight instruments performed completely as designed. On flight 1165, solar sensor outputs were erratic (spurious readouts plus many normal readouts) until 135 seconds of flight time. After 135 seconds of flight time, no useful solar data were obtained. The early normal behavior permitted an orientation determination, which then permitted a sorting out of the normal from the spurious outputs. No loss of information resulted from this failure.

On flight 0611, the usual method of aspect determination which assumes a constant angular momentum vector for the probe and then tests the assumption, failed to confirm its validity. Further analysis of the data showed that consistent interpretation of the aspect data could be obtained only by permitting the angular momentum vector to move at a rate of approximately 2° per second. It has been concluded that the most likely explanation for this situation was that a small leak developed such that a thrust perpendicular to the cylindrical axis existed. A second possible explanation offered is that the cable attached between the negator motor and the probe for imparting tumble failed to release from the probe, thus resulting in a complex non-rigid system. Other explanations are possible, but the leak theory seems best to fit the observations. At any rate, no known loss or deterioration of data were experienced as a result of this problem.

Since no new engineering concepts were tested on these flights, little can be identified as engineering results. The success, however, of eight out of eight shots seems to indicate that the Thermosphere Probe in the configuration used is a reliable space flight instrument.

8. ANALYSIS OF DATA

The telemetered data were recorded on magnetic-tape at the Station 1 (Tel 4) facility. One set of real time paper records, run at one inch per second, were obtained for "quick look" evaluation of the performance of each payload. Other paper records were obtained as required for data reduction as stipulated in the Operations Directives.

Tracking data for trajectory information were obtained from the 0.18 and 19.18 radar facilities.

8.1 TRAJECTORY AND MINIMUM ANGLE OF ATTACK

The trajectory and the velocity information used for the reduction of the data and for the interpretation was obtained by fitting a smooth theoretical trajectory to the radar data. The theoretical trajectory is programmed for computer solution similar to that described by Parker (1962). The output format is shown in Figure 34. The analysis of minimum angle of attack (α) as described by Taeusch, et al. (1965), is also incorporated in the program and the output of the computer furnishes α and $\cos \alpha$ versus time, altitude, etc. Plots of α versus altitude for each of the payloads are given in Figures 26 through 33.

8.2 AMBIENT N_2 DENSITY AND TEMPERATURE

The neutral molecular nitrogen densities for each of the flights were determined from the measured gauge partial densities as described by Spencer, et al. (1965, 1966), by using the basic relationship:

$$n_{aN_2} = \left(\frac{\Delta n_i u_i}{2\sqrt{\pi} V \cos \alpha} \right)_{N_2} K(S, \alpha)$$

where

n_{aN_2} = Ambient N_2 number density

Δn_i = Maximum minus minimum gauge number density during one tumble.

$u_i = \sqrt{\frac{2kT_i}{m}}$ most probable thermal speed of particle inside gauge.

T_i = Gauge wall temperature.

V = Vehicle velocity with respect to earth.

α = Minimum angle of attack for one tumble.

$K(S, \alpha)$ = Correction factor required because of imperfect gauge geometry.
(See Spencer, Taeusch, Carignan, 1965).

ΔI_i , the difference between the maximum (peak) omegatron gauge currentⁱ and the minimum (background) gauge current versus flight time, is shown for a typical flight in Figure 35. The background current is also shown in the figure. The background current is the result of the outgassing of the gauge walls, and the inside density due to atmospheric particles which have enough translational energy to overtake the payload and enter the gauge. In contrast to reports by Moe and Moe (1967), there is laboratory evidence that the background of N_2 , due to outgassing of the gauge walls, is constant for at least one tumble period, and affects both the peak reading and the background reading and therefore does not affect the difference. From calibration data, obtained as discussed in a previous section, the inside number density difference, Δn_i , is computed for the measured current. As described by Spencer, Taeusch and Carignan (1965), the uncertainty in these data is believed to be $\pm 5\%$ relative to other gauges calibrated at the same time on the same system. Much could be written concerning the absolute accuracy which cannot be proved or disproved to anything better than $\pm 25\%$ to date.

By using the thermistor measured gauge wall temperature, u_i , the most probable thermal speed of the particles inside the gauge, is computed. The uncertainty in this measurement is believed to be about $\pm 2\%$ absolute.

V , the vehicle velocity with respect to the earth, is believed to be better than $\pm 1\%$ absolute. It is obtained from the trajectory curve fitting described previously and is the most accurately known quantity obtained from the analysis.

$\cos \alpha$ is obtained from the aspect analysis described by Taeusch, et al. (1965). Since the uncertainty in $\cos \alpha$ depends upon α , for any given uncertainty in α , each particular case and altitude range must be considered separately. However, the upleg angle of attack is typically less than 10° . With an assumed maximum uncertainty in α of $\pm 5^\circ$, this results in less than a $\pm 2\%$ uncertainty in $\cos \alpha$. The low angle of attack data were used as control data in all cases.

$K(S, \alpha)$ for each flight was determined from theoretical and empirical results gathered over a four-year period utilizing data obtained from about ten payloads similar to the ones described herein. Several researchers have contributed to this work (Pearl, John, and Vogel, U., Space Physics Research Laboratory, The University of Michigan, to be published; and Ballance, 1967). In general, the maximum correction to the data is approximately 15%, or $K(S, \alpha) = .85$. These corrections are believed to be better than 2%.

The ambient N_2 number densities versus altitude obtained from the measured quantities described above are tabulated with the derived kinetic temperature in Tables 17 through 24.

The ambient neutral particle temperatures tabulated in Tables 17 through 24 were obtained by integrating the density profiles, which gives the ambient N_2 pressure. The densities and the resulting pressures are then related to the temperatures through the ideal gas law. The assumption that the gas is in hydrostatic equilibrium and behaves as an ideal gas is implicit. Since the temperatures derived depend only on the shape of the density profile and not its magnitude, it is believed that the uncertainty in its magnitude is less than $\pm 5\%$ absolute.

TABLE XVII
 ETR 0381, MUMP 1
 January 24, 1967
 19:34 Z
 14:34 Local (EST)
 Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	618	3.70 x 10 ¹⁰
145	687	2.61
150	743	1.94
155	788	1.49
160	834	1.16 x 10 ¹⁰
165	872	9.24 x 10 ⁹
170	905	7.47
175	939	6.08
180	963	5.03
185	986	4.19
190	1007	3.51
195	1021	2.97
200	1039	2.51
205	1051	2.14
210	1068	1.82
215	1072	1.57
220	1080	1.35
225	1091	1.16
230	1089	1.01 x 10 ⁹
235	1090	8.76 x 10 ⁸
240	1092	7.60
245	1094	6.60
250	1098	5.72
255	1095	4.99
260	1101	4.32
265	1102	3.76
270	1105	3.27
275	1105	2.85
280	1098	2.50
285	1103	2.17
290	1104	1.89
295	1104	1.65
300	1104	1.44
305	1110	1.25
310	1102	1.10 x 10 ⁸
315	1104	9.58 x 10 ⁷
320	1110	8.33 x 10 ⁷

TABLE XVIII

ETR 0611, MUMP 2

January 24, 1967

22:50 Z

17:50 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	656	3.53×10^{10}
145	671	2.72
150	690	2.10
155	706	1.64
160	733	1.27
165	754	1.00×10^{10}
170	769	7.99×10^9
175	785	6.40
180	805	5.13
185	826	4.13
190	840	3.37
195	861	2.74
200	877	2.25
205	896	1.85
210	907	1.54
215	922	1.28
220	934	1.07×10^9
225	940	9.02×10^8
230	948	7.60
235	957	6.41
240	964	5.43
245	969	4.61
250	974	3.92
255	978	3.34
260	981	2.85
265	986	2.43
270	988	2.08
275	990	1.78
280	995	1.52
285	992	1.31
290	997	1.12×10^8
295	1000	9.61×10^7

TABLE XIX

ETR 1165, MUMP 3

January 24, 1967

15:09 Z

10:09 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	630	3.52×10^{10}
145	654	2.65
150	678	2.02
155	694	1.57
160	715	1.22×10^{10}
165	735	9.56×10^9
170	753	7.57
175	770	6.03
180	784	4.85
185	800	3.90
190	810	3.18
195	822	2.59
200	832	2.12
205	843	1.74
210	855	1.43
215	866	1.18×10^9
220	874	9.80×10^8
225	881	8.16
230	893	6.77
235	906	5.63
240	917	4.70
245	924	3.95
250	933	3.32
255	940	2.80
260	950	2.36
265	956	2.00
270	959	1.70
275	968	1.44
280	969	1.23
285	982	1.04×10^8
290	976	8.97×10^7
295	983	7.64
300	982	6.56
305	986	5.61
310	988	4.81
315	991	4.12
320	990	3.55×10^7

TABLE XX
 ETR 1942, MUMP 4
 April 25, 1967
 06:30 Z
 01:30 Local (EST)
 Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
145	591	3.70 x 10 ¹⁰
150	628	2.74
155	658	2.04
160	690	1.55
165	720	1.18 x 10 ¹⁰
170	747	9.19 x 10 ⁹
175	774	7.22
180	796	5.77
185	816	4.61
190	831	3.74
195	846	3.07
200	860	2.51
205	875	2.06
210	887	1.70
215	898	1.41
220	906	1.18 x 10 ⁹
225	915	9.82 x 10 ⁸
230	922	8.27
235	927	7.00
240	931	5.92
245	935	5.00
250	937	4.23
255	939	3.60
260	940	3.06
265	941	2.60
270	941	2.21
275	942	1.88
280	942	1.60
285	942	1.36
290	942	1.17 x 10 ⁸
295	942	9.90 x 10 ⁷
300	942	8.45
305	942	7.20
310	942	6.08
315	942	5.19
320	942	4.41 x 10 ⁷

TABLE XXI

ETR 4803, MUMP 5

April 25, 1967

19:00 Z

14:00 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	616	4.81×10^{10}
145	654	3.56
150	693	2.65
155	736	2.00
160	777	1.54
165	814	1.20×10^{10}
170	848	9.54×10^9
175	880	7.69
180	907	6.24
185	931	5.13
190	951	4.26
195	969	3.55
200	983	2.99
205	997	2.52
210	1010	2.14
215	1021	1.81
220	1030	1.54
225	1037	1.32
230	1044	1.13×10^9
235	1049	9.66×10^8
240	1053	8.34
245	1057	7.20
250	1060	6.21
255	1062	5.38
260	1065	4.63
265	1067	4.01
270	1069	3.47
275	1071	3.01
280	1072	2.61
285	1073	2.27
290	1075	1.97
295	1076	1.70
300	1077	1.48
305	1078	1.29
310	1080	1.12×10^8
315	1081	9.60×10^7
320	1082	8.29×10^7

TABLE XXII

ETR 1828, MUMP 6

January 24, 1967

11:51 Z

06:51 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	573	3.25 x 10 ¹⁰
145	625	2.29
150	669	1.68
155	698	1.28 x 10 ¹⁰
160	724	9.90 x 10 ⁹
165	743	7.80
170	759	6.20
175	768	5.00
180	781	4.02
185	787	3.27
190	801	2.64
195	808	2.16
200	819	1.76
205	824	1.45
210	833	1.19 x 10 ⁹
215	837	9.85 x 10 ⁸
220	844	8.13
225	847	6.75
230	851	5.61
235	854	4.67
240	862	3.87
245	859	3.25
250	863	2.71
255	868	2.26
260	876	1.88
265	877	1.58
270	876	1.33
275	875	1.12 x 10 ⁸
280	882	9.35 x 10 ⁷
285	880	7.90
290	880	6.65
295	873	5.65
300	880	4.72
305	880	3.98
310	882	3.35
315	884	2.82
320	885	2.38 x 10 ⁷

TABLE XXIII

ETR 0851, MUMP 7

January 24, 1967

03:00 Z

22:00 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	594	3.59 x 10 ¹⁰
145	635	2.60
150	665	1.95
155	685	1.50
160	707	1.16 x 10 ¹⁰
165	718	9.18 x 10 ⁹
170	731	7.27
175	743	5.78
180	754	4.63
185	762	3.73
190	774	3.00
195	786	2.42
200	794	1.97
205	800	1.61
210	811	1.31
215	823	1.07 x 10 ⁹
220	831	8.79 x 10 ⁸
225	845	7.20
230	850	5.97
235	855	4.96
240	863	4.11
245	866	3.43
250	875	2.85
255	877	2.39
260	881	2.00
265	883	1.68
270	887	1.41
275	894	1.18
280	890	1.00 x 10 ⁸
285	894	8.41 x 10 ⁷
290	894	7.10
295	894	6.00
300	895	5.07 x 10 ⁷

TABLE XXIV

ETR 1474, MUMP 8

January 24, 1967

09:00 Z

04:00 Local (EST)

Cape Kennedy, Florida

ALTITUDE (km)	TEMPERATURE (°K)	DENSITY (part/cc)
140	504	3.75×10^{10}
145	544	2.57
150	596	1.78
155	639	1.29×10^{10}
160	676	9.61×10^9
165	707	7.33
170	736	5.67
175	762	4.45
180	785	3.53
185	802	2.84
190	817	2.30
195	828	1.88
200	840	1.54
205	847	1.27
210	855	1.05×10^9
215	860	8.72×10^8
220	865	7.25
225	868	6.05
230	872	5.05
235	873	4.23
240	876	3.54
245	877	2.97
250	879	2.49
255	876	2.10
260	879	1.76
265	879	1.48
270	884	1.24
275	888	1.04×10^8
280	885	8.80×10^7
285	885	7.42
290	884	6.26
295	884	5.28
300	885	4.45
305	884	3.76
310	882	3.18
315	883	2.68
320	885	2.26×10^7

LAUNCH TIME (GMT)

YEAR 1967
DAY 115
HOUR 19
MINUTE 0
SECOND .000

INITIAL CONDITIONS

TIME 70.000 SECONDS FROM LAUNCH
ALTITUDE 416538.7 FT
RANGE 88146.3 FT
VELOCITY 6536.1 FT/SEC
FLIGHT PATH ANGLE 76.6289 DEGREES UP FROM LOCAL HORIZONTAL PLANE
AZIMUTH 76.1700 DEGREES EAST OF LOCAL NORTH
LONGITUDE -80.2596 DEGREES (+EAST)
LATITUDE 28.5122 DEGREES (+NORTH)

NO WIND SPECIFIED

CONE CORRECTION -.70

MOMENTUM VECTOR INPUT BY SPECIFYING PHI LS = 62.0 AND THETA LS = 129.6
COMPUTED MOMENTUM VECTOR IN EARTH FIXED COORDINATES IS .299509 .883184 -.360943

MOMENTUM VECTOR INPUT BY SPECIFYING PHI LS = 172.0 AND THETA LS = 129.6
COMPUTED MOMENTUM VECTOR IN EARTH FIXED COORDINATES IS -.401072 -.008207 -.916010

PEAK PARAMETERS

TIME	ALTITUDE F ALTITUDE M	ALPHA	V COS ALPHA	PHI V	RANGE F RANGE M	VELOCITY F VELOCITY M	VXFX VYFX	VZFX	AZIMUTH ELEVATION	LATITUDE LONGITUDE
286.79	1098205	30.90	360.09	103.66	384318	1376.80	1339.35	-31.17	77.387	28.699
334733		-21.10	391.50	-177.20	117140	419.65	317.15		-.000	-79.360

Figure 34. Trajectory program output format.

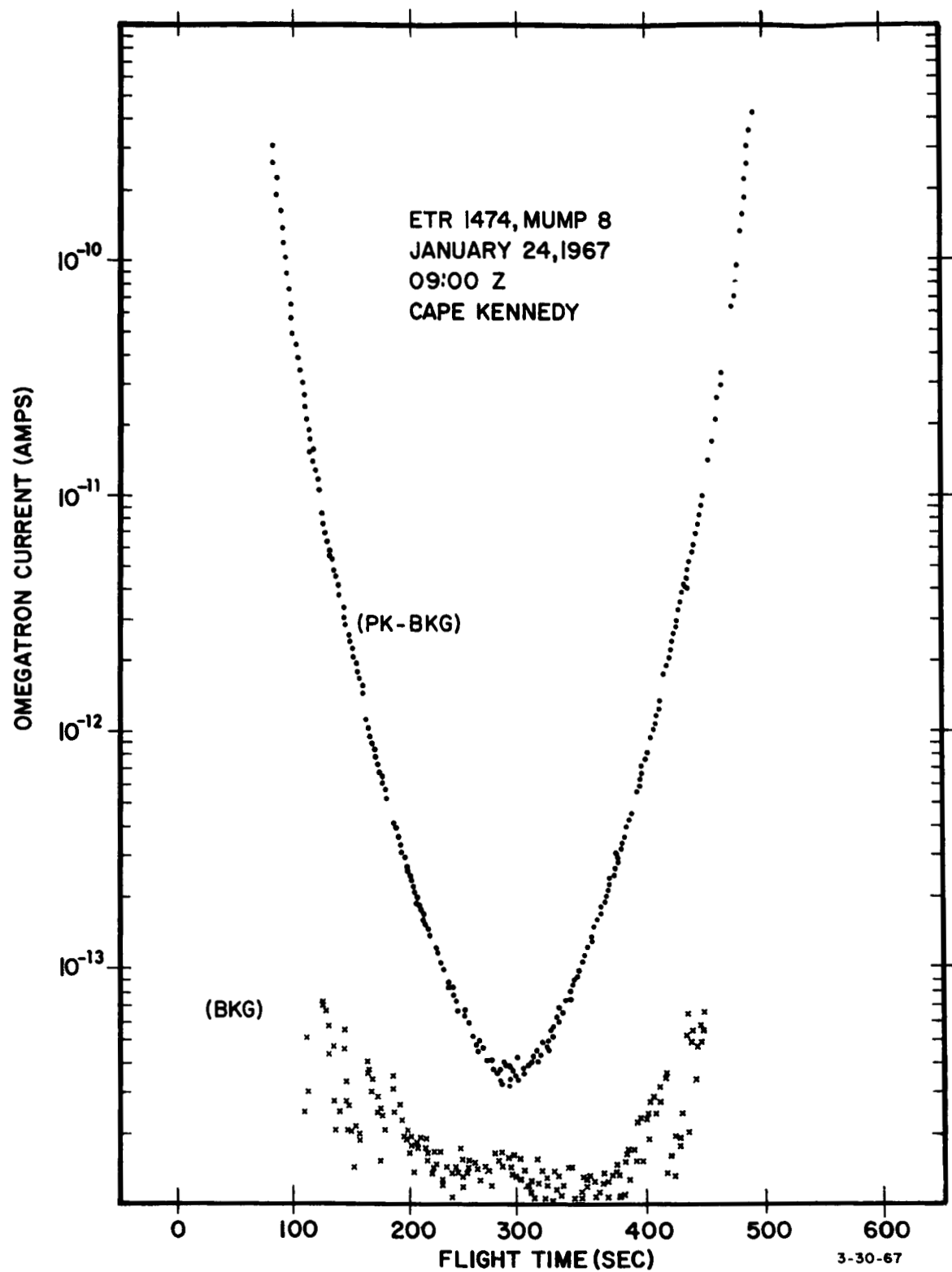


Figure 35. Omegatron current vs. flight time.

8.3 ELECTRON TEMPERATURE AND DENSITY

The cylindrical Langmuir probe technique which was used in this series of experiments has been described a number of times before (e.g., Brace, et al., 1963; Nagy, et al., 1963; Spencer, et al., 1965); therefore only a brief review of the data reduction technique will be given here. The equations for the current collected by a stationary cylindrical probe immersed in a plasma were derived by Mott-Smith and Langmuir (1926). Recently Kanai (1964) extended this work to moving cylindrical probes. The thermal velocity of the electrons is very large in comparison with typical rocket velocities; therefore, if the effect of sheath distortion is neglected, the probe can be considered stationary for electron current calculations. The dimension of the sheath which surrounded the collector is of the order of the Debye length, which is inversely proportional to the electron density and therefore the sheath will be the smallest in the daytime F region. The Debye length corresponding to typical daytime F region conditions is of the order of 0.3 cm; since the radius of the collector used in this experiment is only 0.027 cm, a large a/r ratio (sheath radius to probe radius) results. The retarded and accelerated electron current equations under these conditions are, respectively

$$I_r = \left(\frac{kT_e}{2\pi m_e} \right)^{1/2} N_e q A \exp(V_o) \quad (1)$$

$$I_a = \left(\frac{kT_e}{2\pi m_e} \right)^{1/2} N_e q A \left[2 \left(\frac{V_o}{\pi} \right)^{1/2} + \exp(V_o) \operatorname{erfc}(V_o^{1/2}) \right] \quad (2)$$

where

- k = Boltzmann's constant.
- T_e = electron temperature.
- m_e = mass of an electron.
- N_e = number density of electrons.
- q = electronic charge
- A = collector area.
- $V_o = qV_{pp}/kT$.
- V_{pp} = potential difference between the probe and the ambient plasma = $V_{ap} + V_r$.
- V_{ap} is applied voltage.
- V_D is potential of the reference with respect to the plasma.
- $\operatorname{erfc}(x)$ = complementary error function = $1 - (2/\pi^{1/2}) \int_0^x \exp[-\beta^2] d\beta$.

The method of electron temperature reduction from the retarding potential current characteristics, used on previous occasions, was outlined in the report by Taeusch, et al., (1965). In this method the retarded electron current is plotted on a semilog paper, and the temperature is obtained from the slope of the resulting straight line; such a typical plot from flight ETR 1474 is shown in Figure 36. Since this technique is very cumbersome and time consuming and the computerized system for reduction of the data was not yet operational, the following "template method" was used to reduce the bulk of the data.

The natural logarithm of the ratio of two points on the retarded electron current characteristics is:

$$\ln C = \frac{q}{k} \frac{\Delta V_{ap}}{T_e}$$

$$C = \frac{I_{e2}}{I_{e1}} = \text{ratio of electron currents}$$

$$\Delta V_{ap} = V_{ap2} - V_{ap1}$$

$$V_{ap2} = \text{applied voltage corresponding to } I_{e2}$$

$$V_{ap1} = \text{applied voltage corresponding to } I_{e1}$$

Since the retarded electron current is exponential (Equation 1), ΔV_{ap} will be the same for all points having the same ratio C . Given a C we can therefore determine ΔV_{ap} for different temperatures and draw a grid as shown in Figure 37.

The current collected by the probe is not the electron but the total current, so we have to apply the same corrections as used on previous occasions. The ion saturation current is extrapolated by a straight line and it is assumed that the difference between the net current and the straight line is the electron current. This leads to the construction of a template as shown in Figure 38. Here instead of calibrating the grids in terms of ΔV_{ap} we did it in terms of temperature allowing direct determination of the electron temperatures. The templates were made of transparent paper by allowing them to be used directly on the paper record of the telemetered data. The majority of the temperature information was obtained in this manner. Numerous data curves were also reduced by using the conventional semi-log method for the sake of comparison, but no detectable difference in the results was observed.

The accelerated electron current is two orders of magnitude higher than the retarded ion current; therefore, the effect of the latter on the total current is negligible. The two unknown quantities in the accelerated electron current, Equation (2), are the electron density, N_e , and the reference potential, V_r . Any two points from this portion of the curve are, therefore, sufficient to solve for the unknowns (Nagy and Faruqi, 1965). Templates based on this method were used to obtain the electron density results from the series of flights discussed here.

When $V_0 \gg 1$ Equation (2) simplifies to

$$I_{ea} \approx \left(\frac{kT_e}{2\pi m_e} \right)^{1/2} N_e q A \frac{2}{\pi^{1/2}} V_0^{1/2} \quad (3)$$

For typical ionospheric conditions (e.g., $T_e = 2000^\circ \text{ K}$) V_0 is 5.79 V when V_{ap} is 1 V; therefore, Equation (3) is applicable when $V_{ap} > 1$ V. Let us consider two points on the accelerated electron current characteristics corresponding to $(V_{ap} - V_r)$ equal to 2 V and 1 V respectively. The ratio of the currents corresponding to these two voltages is $\sqrt{2}$ according to Equation (3). Two vertical lines, separated by a distance, corresponding to a difference of 1 V in the applied voltage, as shown in Figure 39, provides a template which can be used to determine the electronic density directly from the characteristic curves. The density is obtained by placing the template on the data curve and shifting it horizontally until the curve crosses the vertical lines at the points which correspond to the same electron density (see Figure 40). This value then corresponds to the solution of Equation (3) for N_e .

The charged particle results obtained from the electrostatic probe experiments of MUMPS 1, 2, 3, 4, 5, 6, 7, and 8 are shown in Figures 41 through 48, respectively.

8.4 GEOPHYSICAL INDICES

The 10.7 cm solar flux ($F_{10.7}$) and the geomagnetic activity indices (a_p) for the appropriate periods during launch day are shown in Figures 49, 50, and 51.

LOG CURRENT vs. POTENTIAL FOR ESP

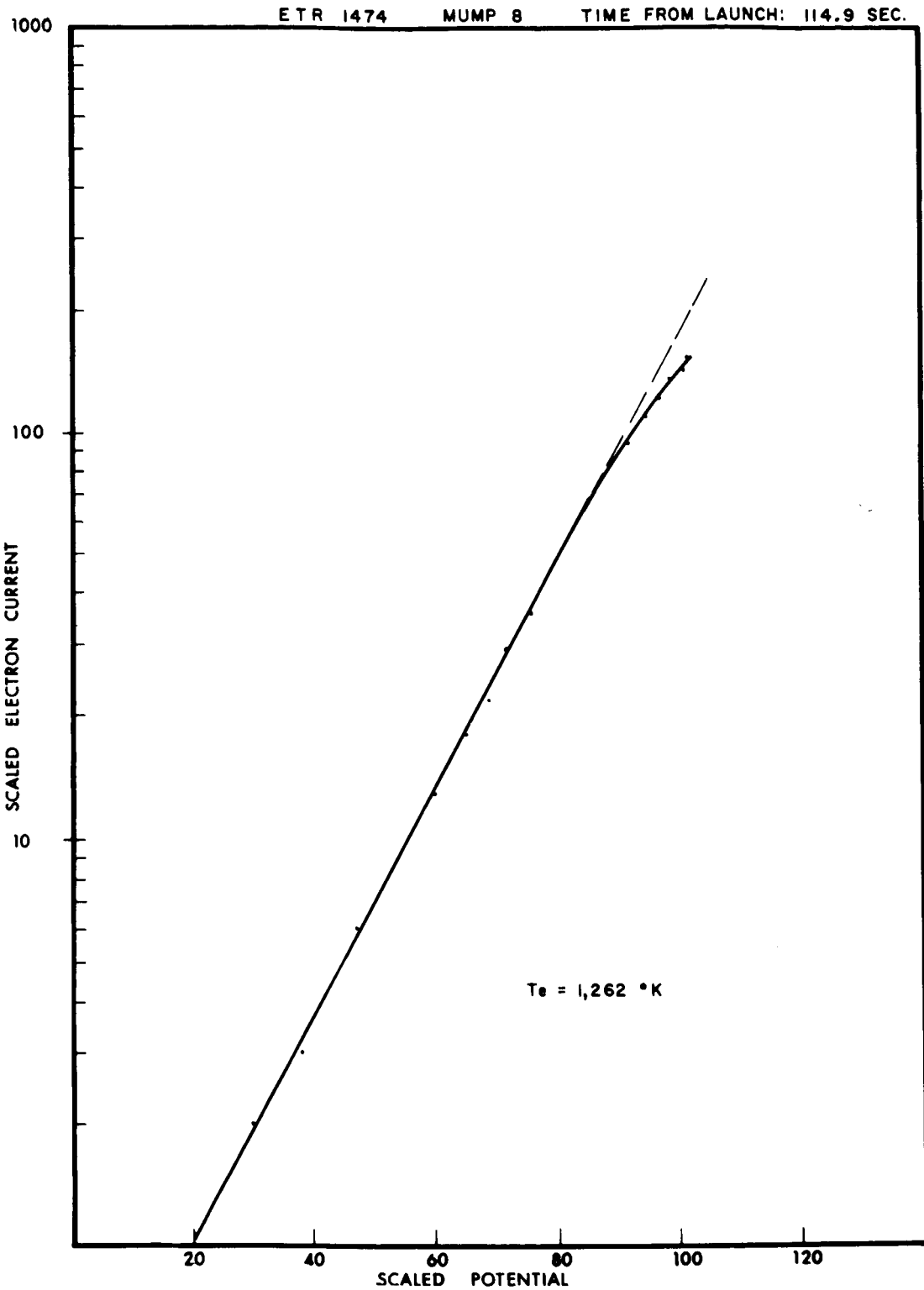


Figure 36. Typical log current vs. potential plot from the electrostatic probe experiment of MUMP 8.

ΔV_{ep} CORRESPONDS
TO 200°K

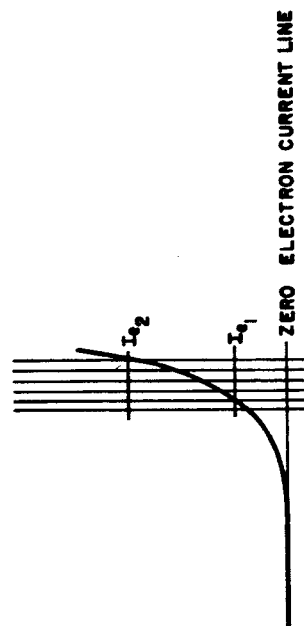


Figure 37. Electron temperature template with no ion current correction.

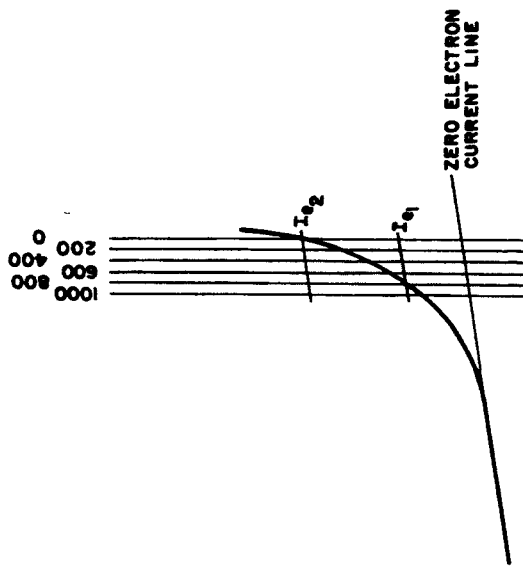


Figure 38. Electron temperature template with ion current correction.

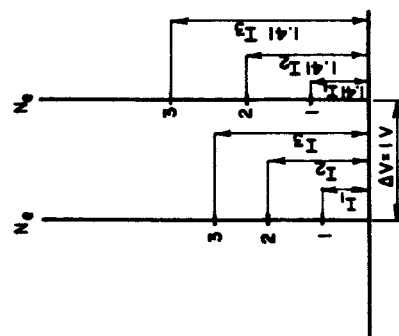


Figure 39. Basic electron density template.

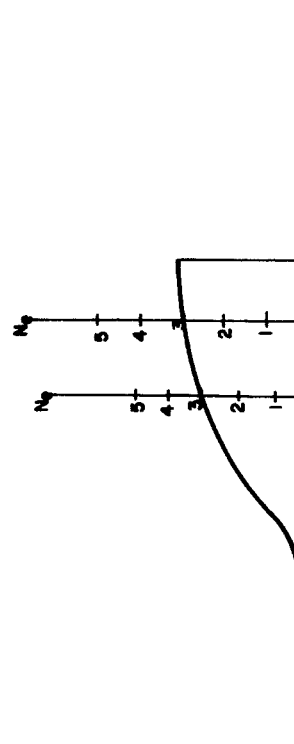


Figure 40. Electron density template superimposed on data curve.

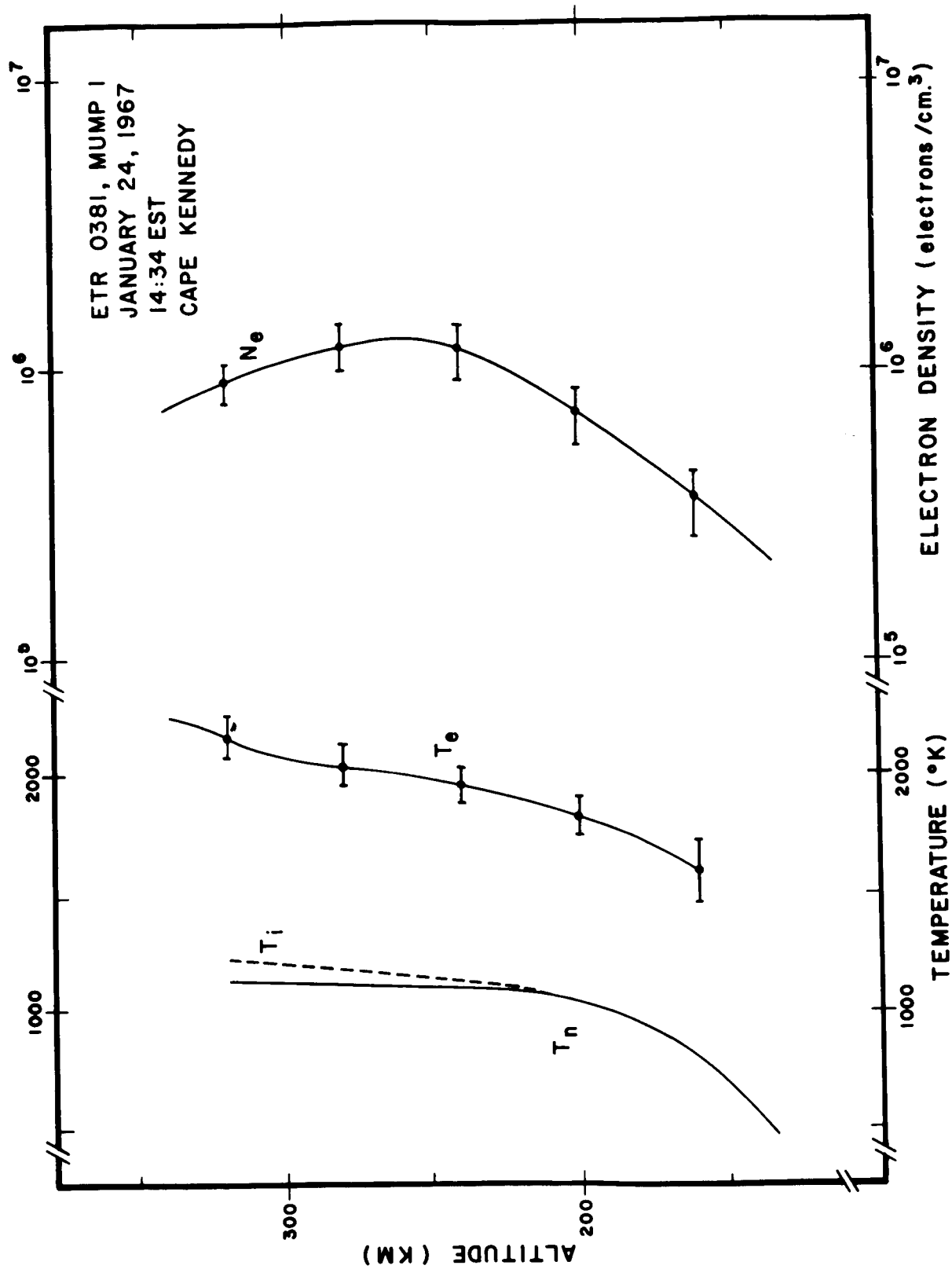


Figure 41. Charged particle results from the electrostatic probe experiment of MUMP 1.

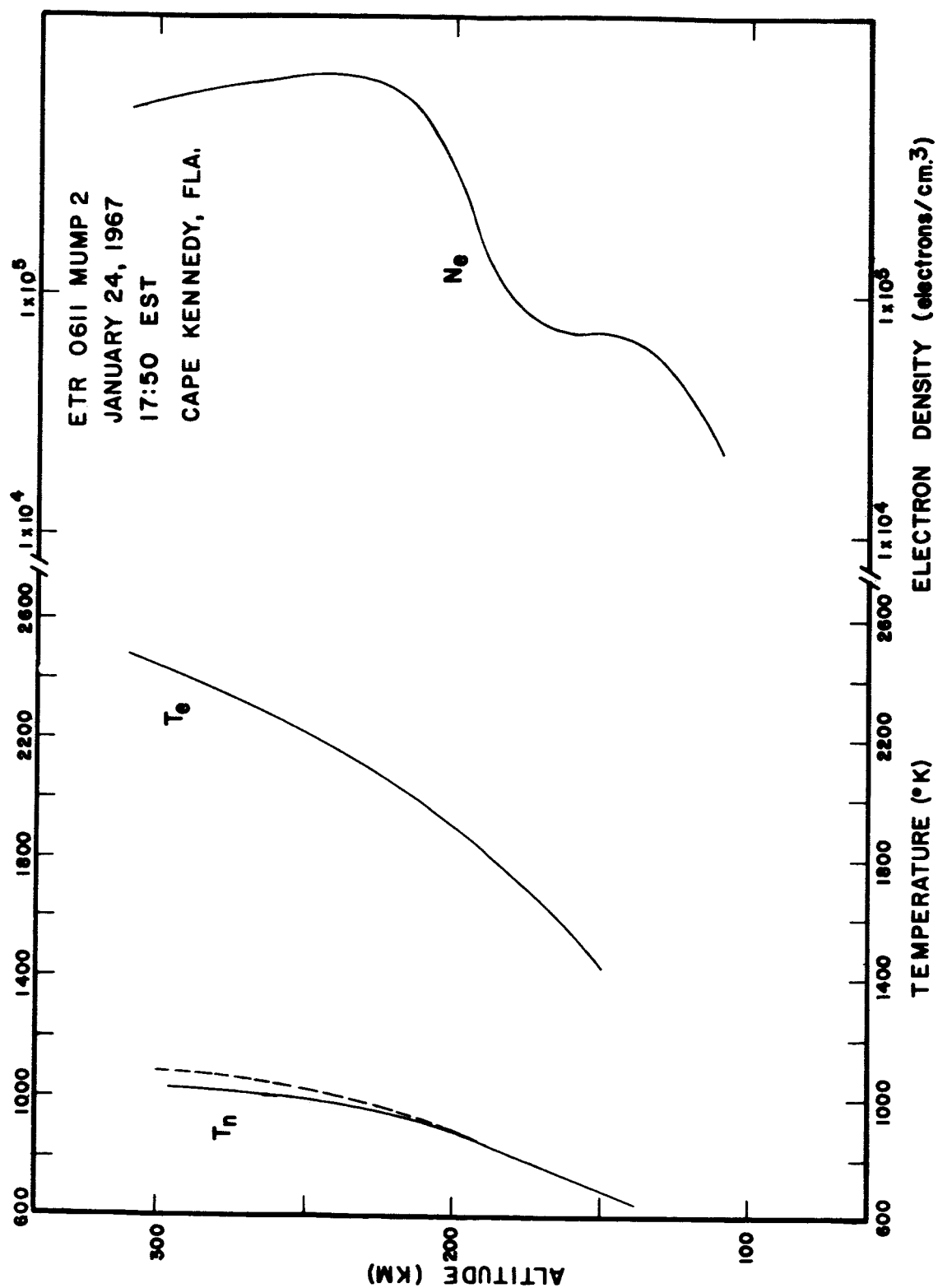


Figure 42. Charged particle results from the electrostatic probe experiment of MUMP 2.

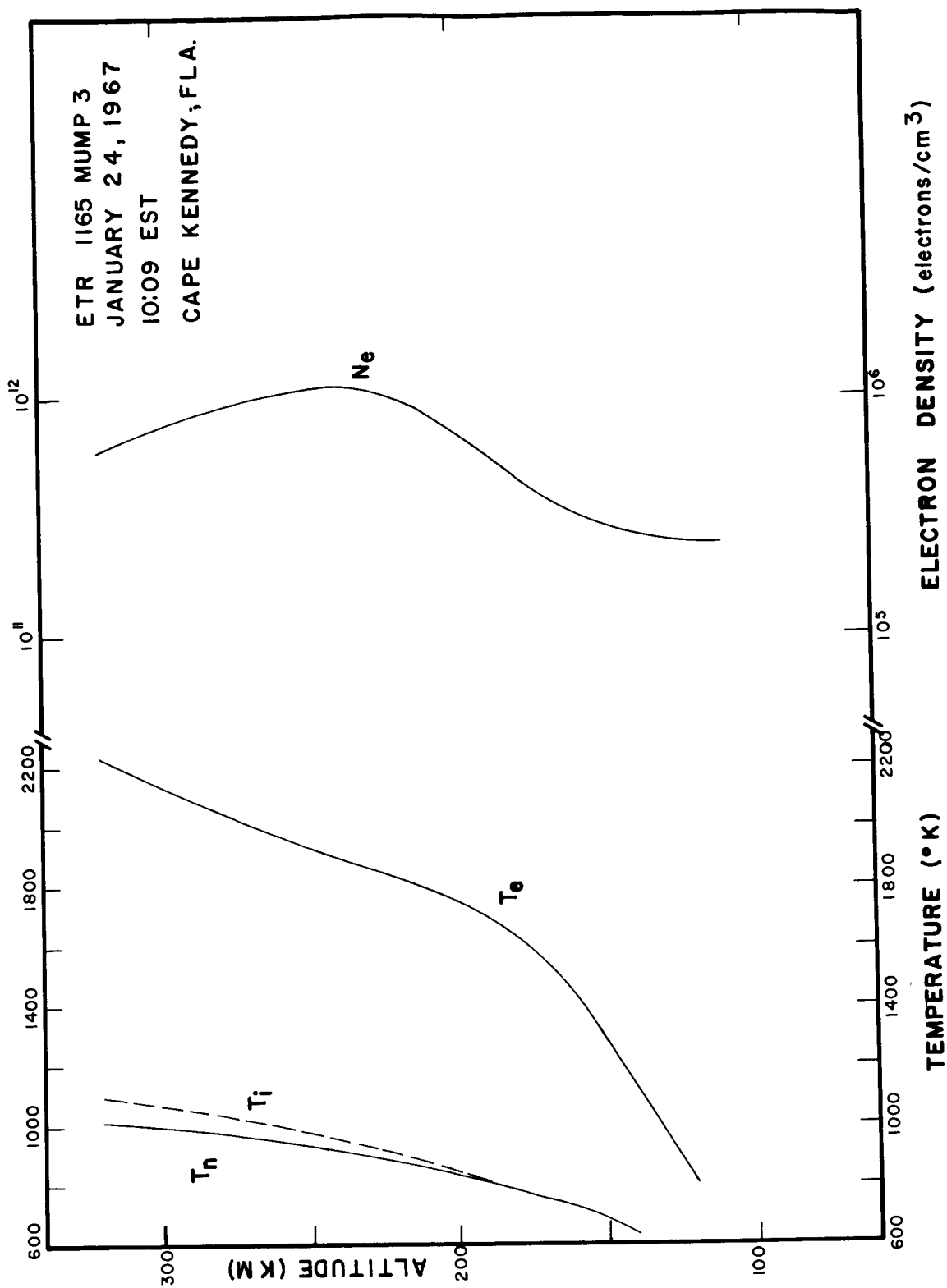


Figure 43. Charged particle results from the electrostatic probe experiment of MUMP 3.

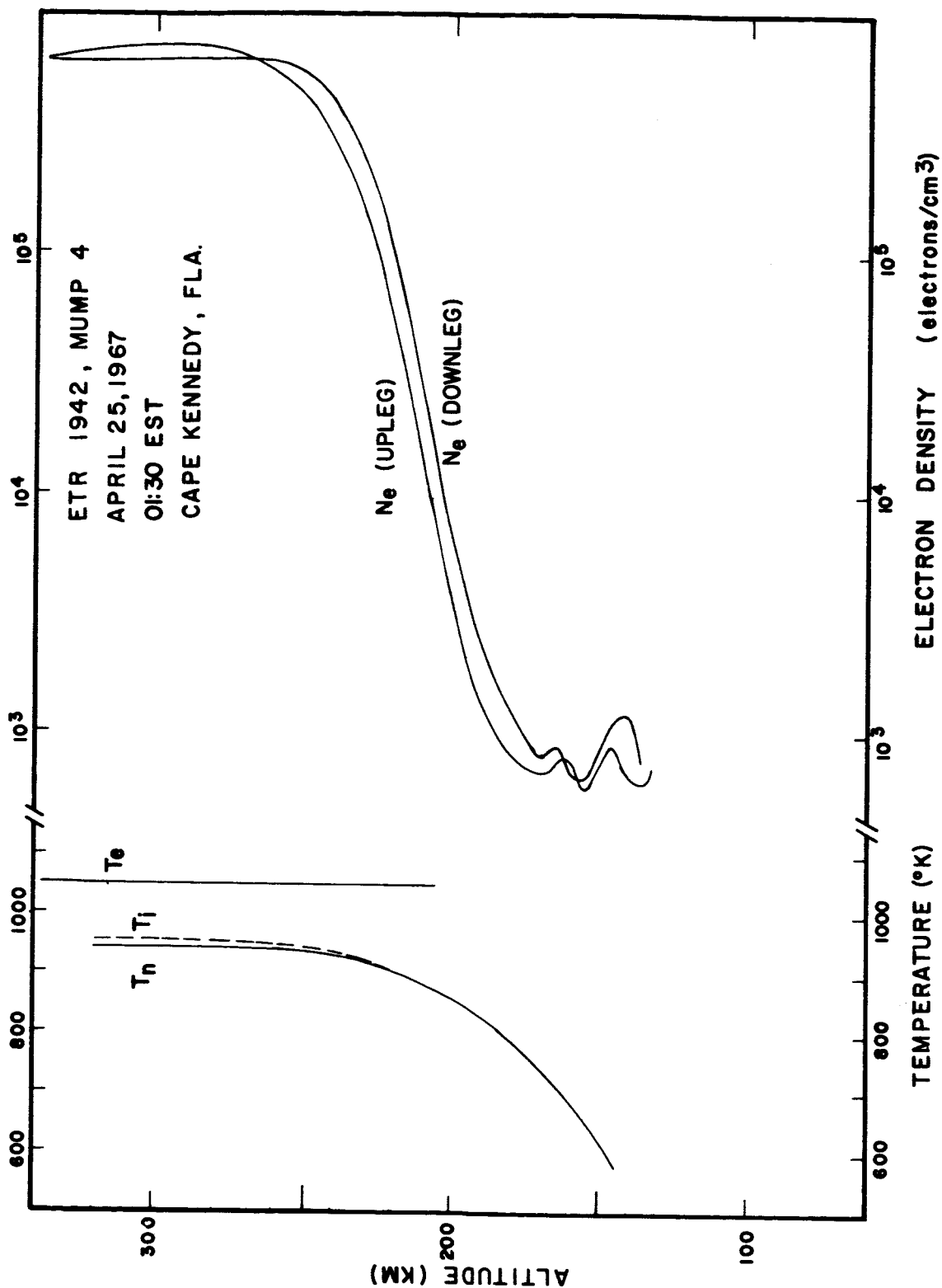


Figure 44. Charged particle results from the electrostatic probe experiment of MUMP 4.

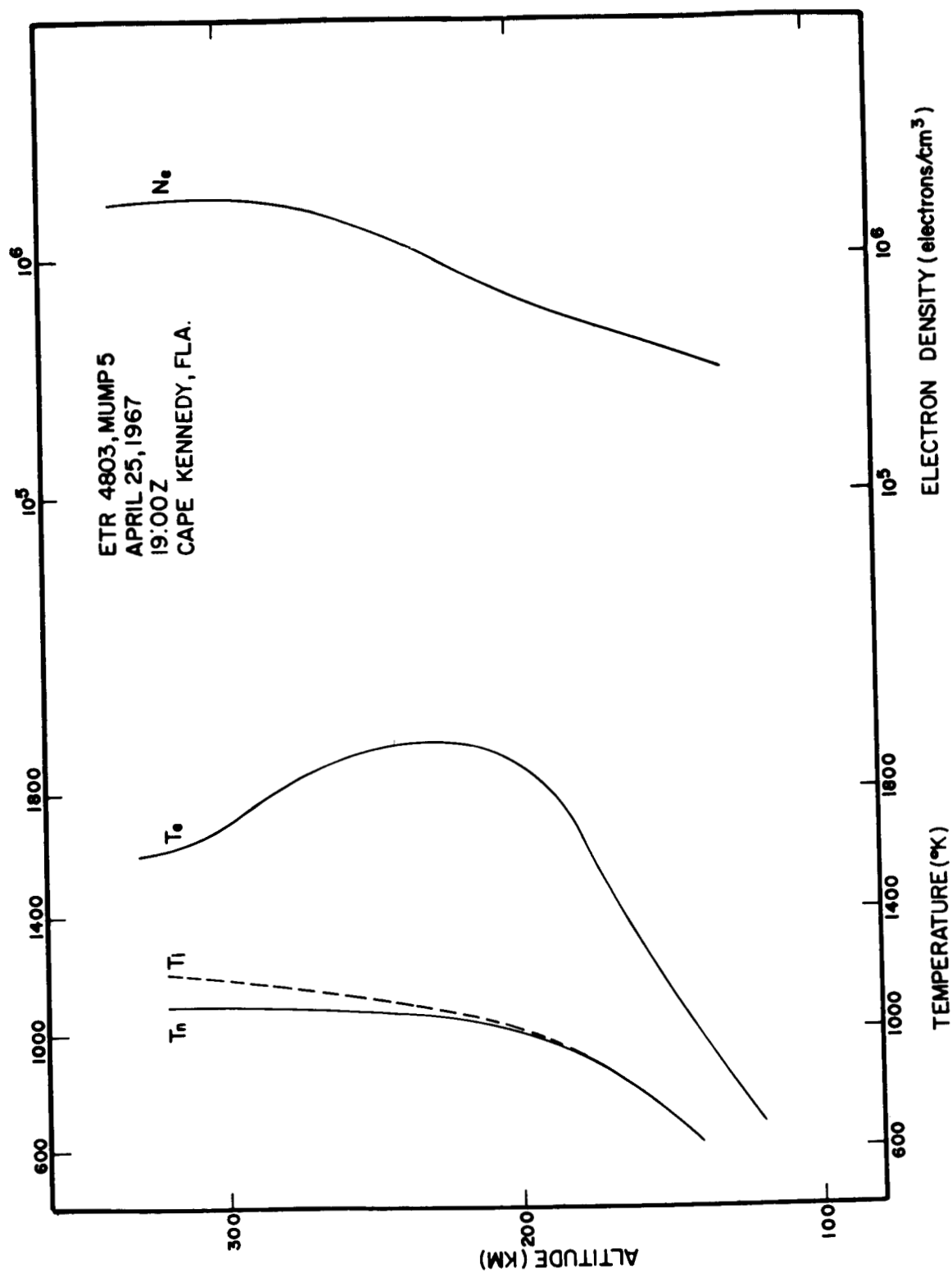


Figure 45. Charged particle results from the electrostatic probe experiment of MUMP 5.

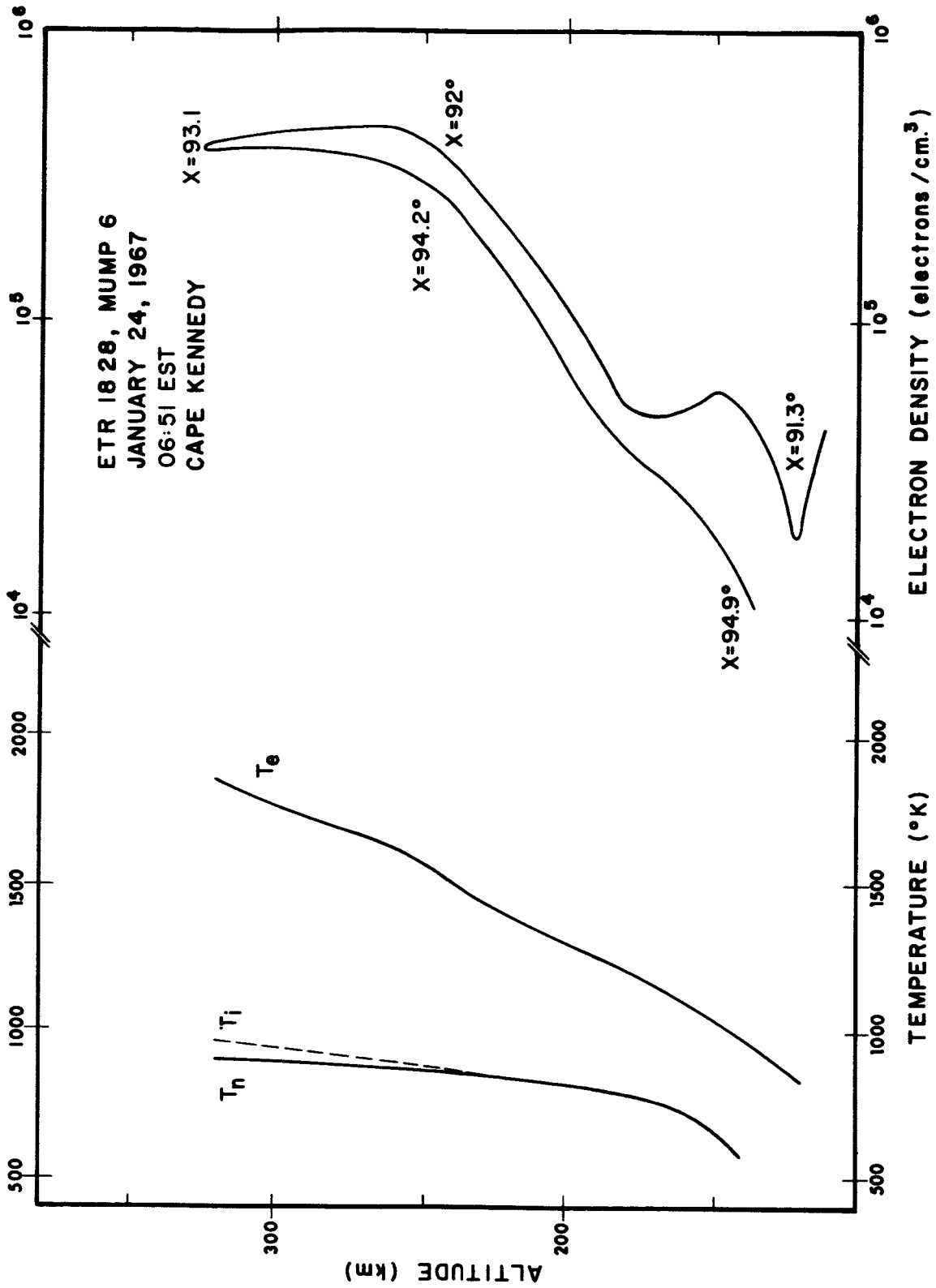


Figure 46. Charged particle results from the electrostatic probe experiment of MUMP 6.

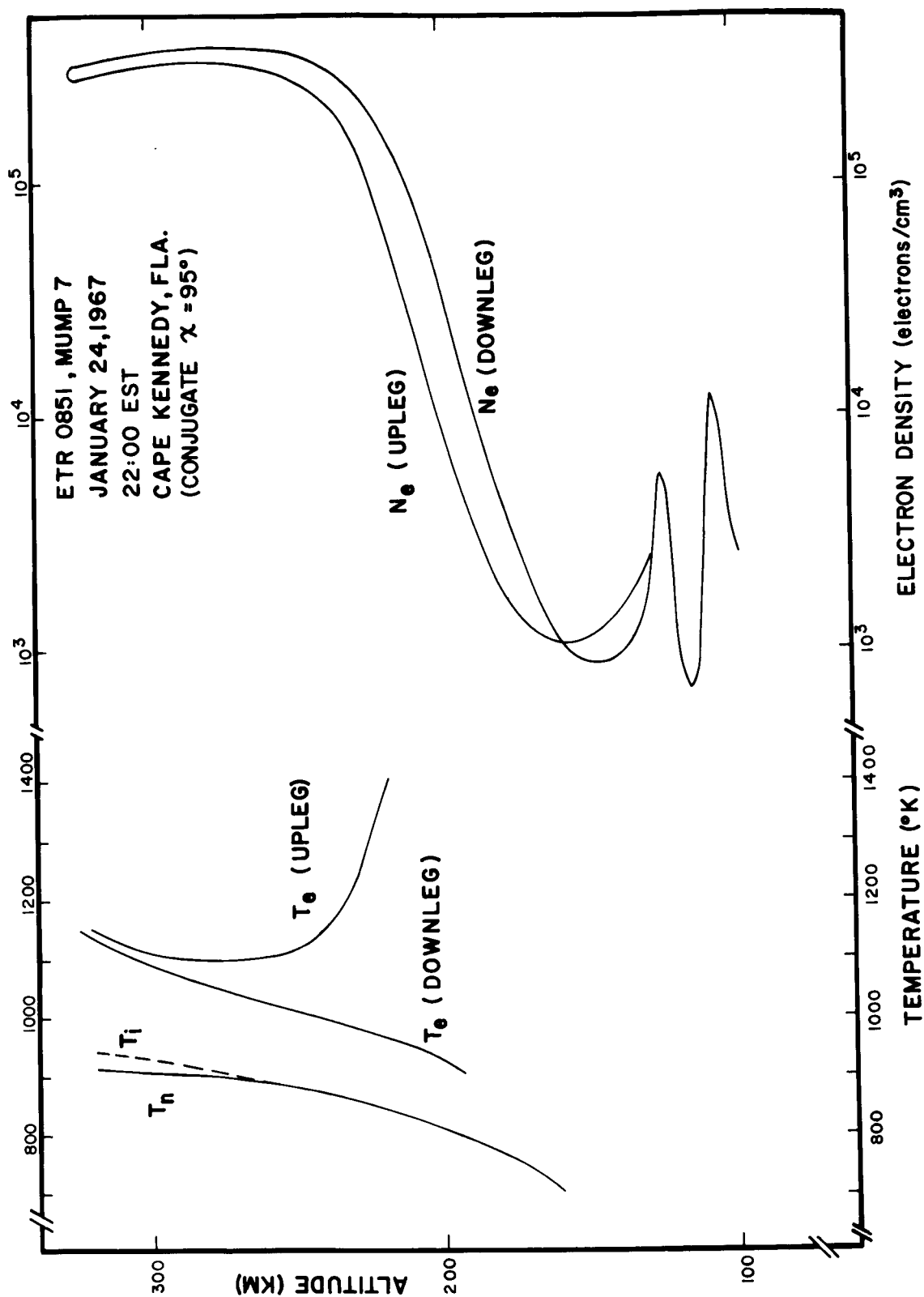


Figure 47. Charged particle results from the electrostatic probe experiment of MUMP 7.

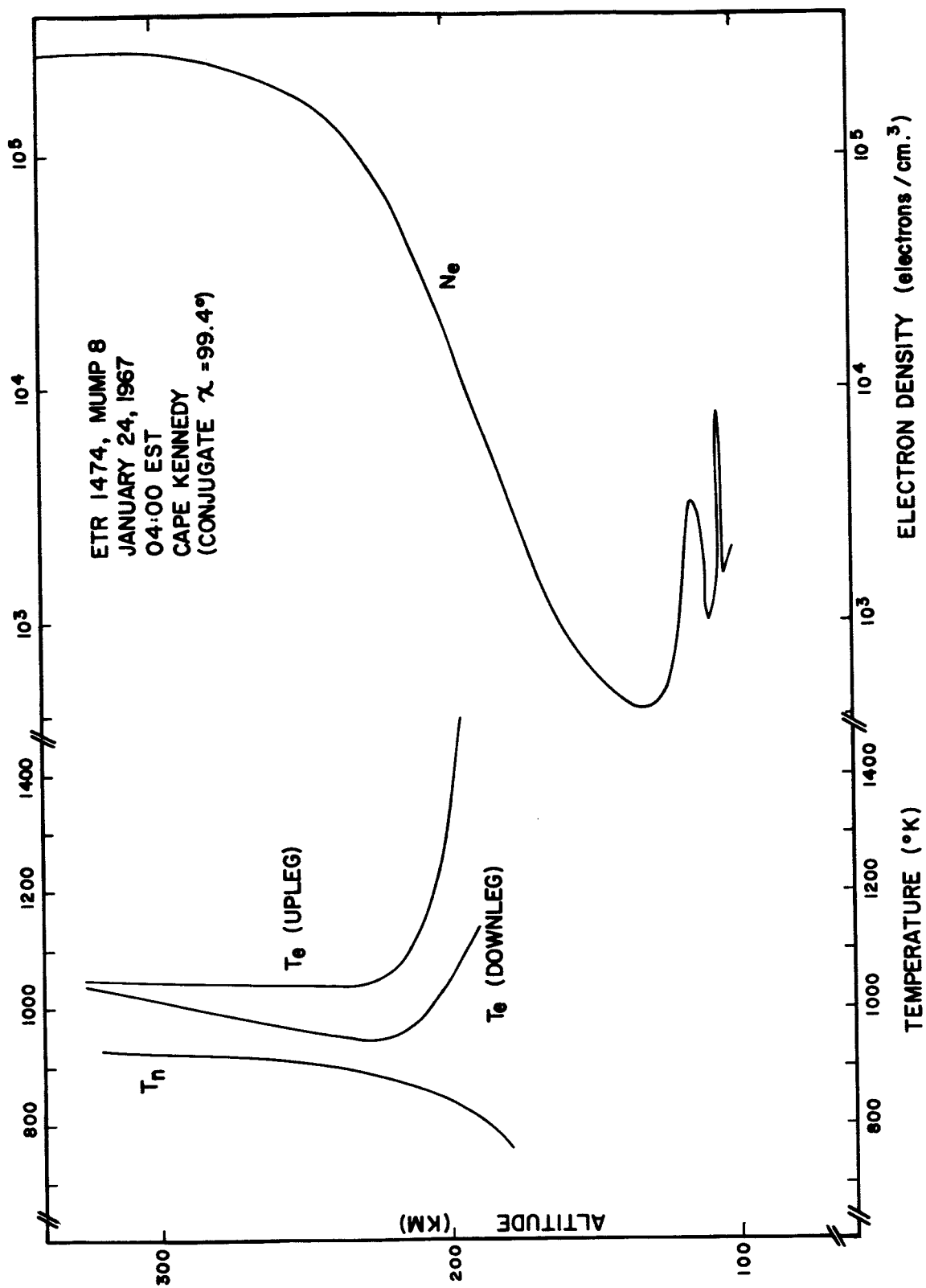


Figure 48. Charged particle results from the electrostatic probe experiment of MUMP 8.

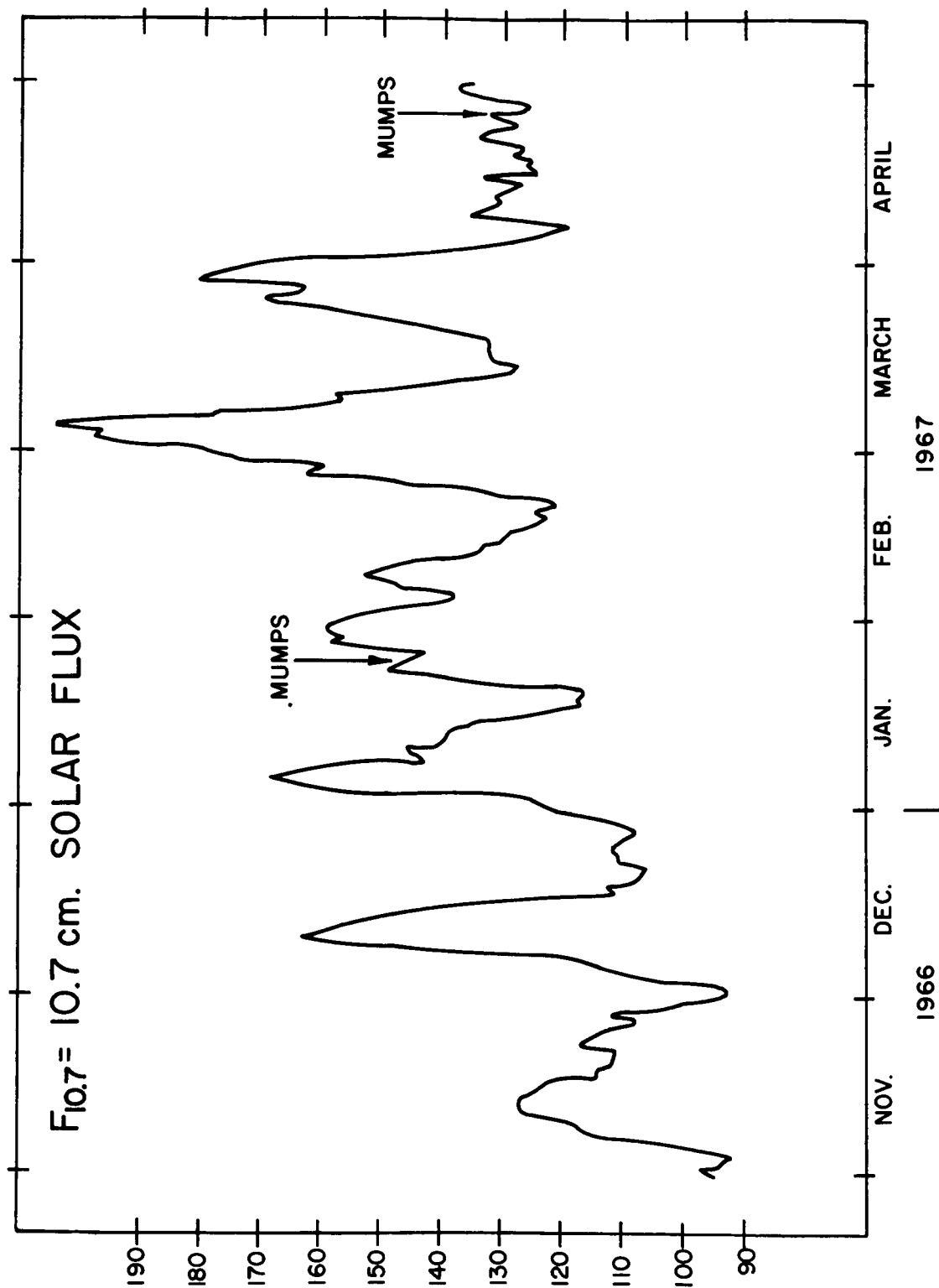


Figure 49. The solar flux at 10.7 cm wavelength.

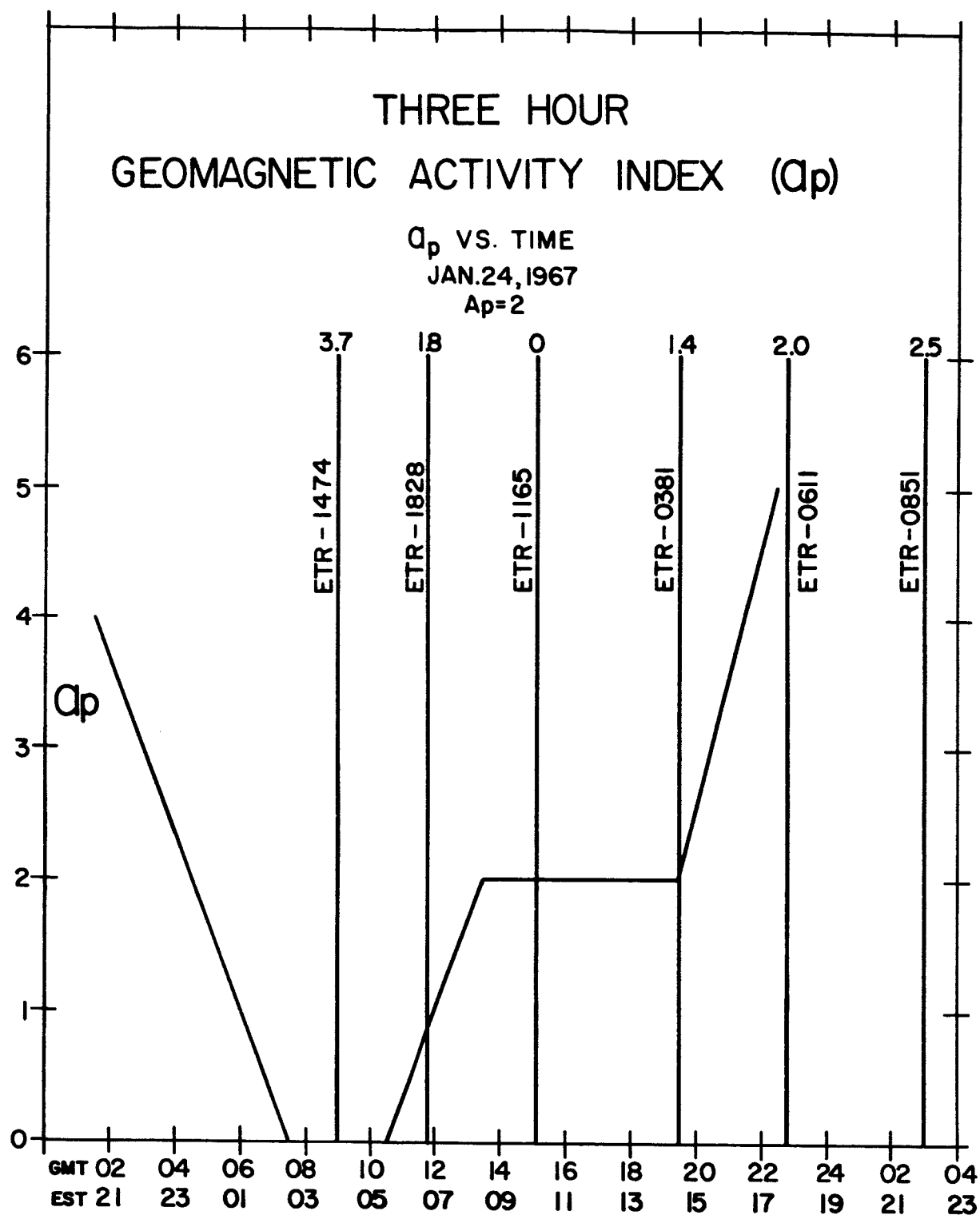


Figure 50. Three-hour geomagnetic activity index (a_p) January 24, 1967).

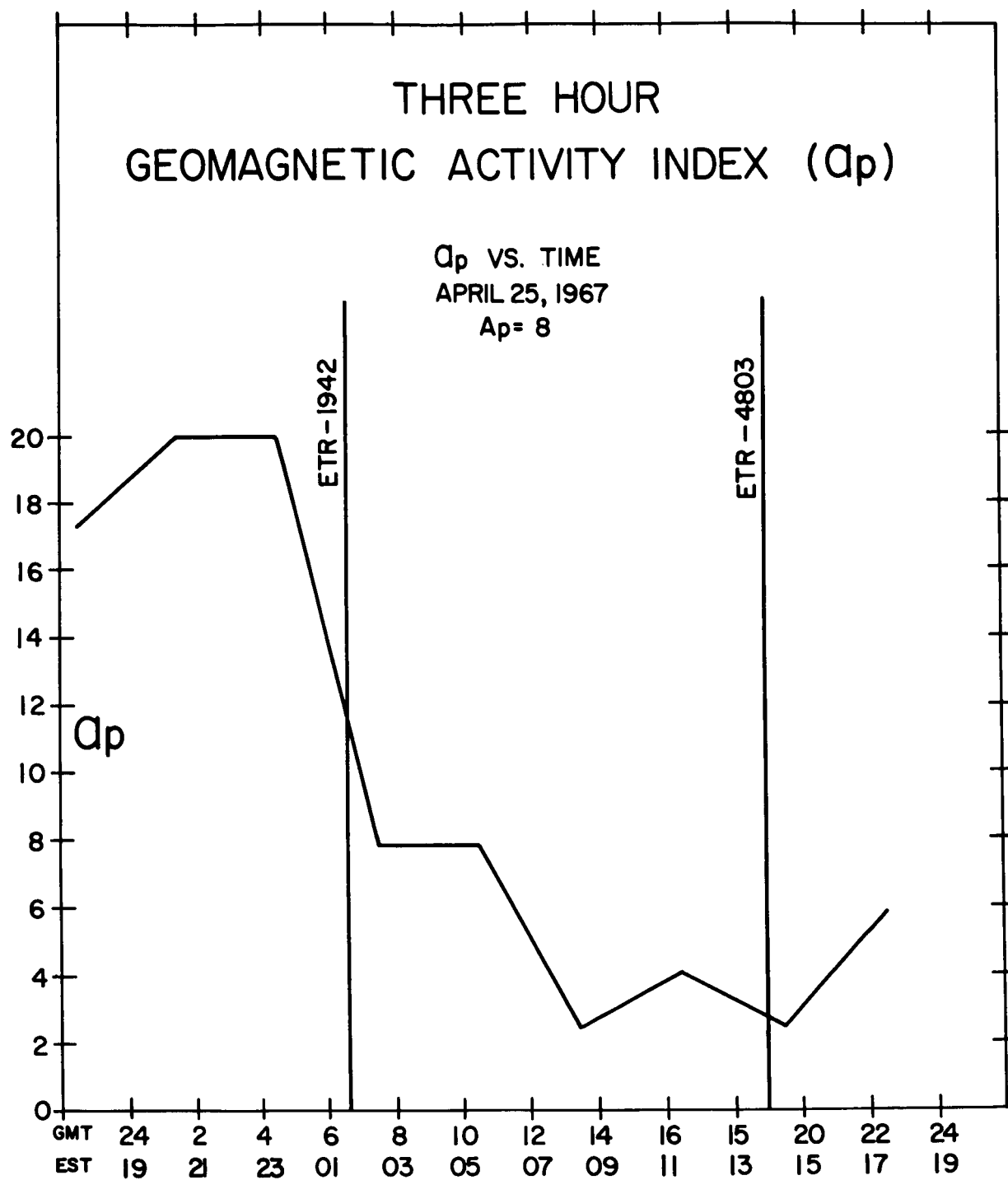


Figure 51. Three-hour geomagnetic activity index (a_p) (April 25, 1967).

9. CONCLUSIONS

The payload design and successful launching of eight Marshall-University of Michigan probes have been described in the present report. These probes provided data which permitted the determination of the neutral molecular nitrogen density and temperature and the electron density and temperature in the altitude region between approximately 140 and 320 km. Six of the payloads provided data during one diurnal cycle on January 24, 1967. Two additional payloads provided data on the maximum and on the minimum of the diurnal variation on April 25, 1967. The purpose of the two sets of launches was to obtain data which would bear on the diurnal variation of the atmospheric parameters, and consequently be of value in the development of future model atmospheres. The data have been reported at the July meeting of COSPAR in London, England, and the paper has been accepted for publication in Space Research VIII. A summary discussion of the preliminary findings and significant points of interest are included in the following subsections.

9.1 NEUTRAL MOLECULAR NITROGEN DENSITY AND TEMPERATURE

The theory of the measurement, of the reduction of raw data, and of the probable errors for each of the nitrogen, density, and temperature altitude profiles was discussed in the previous section. Figures 52 and 53 give the congeries of these data. Of more interest here, however, are the variations with time of day as given in Figures 54 and 55. The figures also show several data points taken from the CIRA 1965 model 4 and also show the variation as is predicted by Jacchia (1964, 1965a,b) for the appropriate 10.7 cm solar flux and geomagnetic activity levels. As can be seen, the density values predicted by the two models are approximately a factor of two greater than the measured values. This discrepancy between gauge measurements and drag measurements has persisted for many years. However, the temperature predictions made by Jacchia (1964, 1965a,b) are in excellent agreement with the temperature values determined from the measured density profiles.

Even though these data are relatively new and much work remains to be done, some preliminary conclusions are as follows:

1. Densities determined by satellite drag techniques are typically on the order of a factor of two higher than those determined by density gauge and mass spectrometer techniques.
2. CIRA 1965 model nighttime temperatures are in good agreement with those derived by direct measurements, but the daytime model temperatures are consistently too high at the level of solar activity used for the comparison.

3. The atmospheric temperatures and densities below 200 km are more variable than current models predict.
4. The Jacchia empirical formulae, which predict exospheric temperatures as a function of geomagnetic activity, solar flux, and time of day and year, are consistent with the mass spectrometer results.

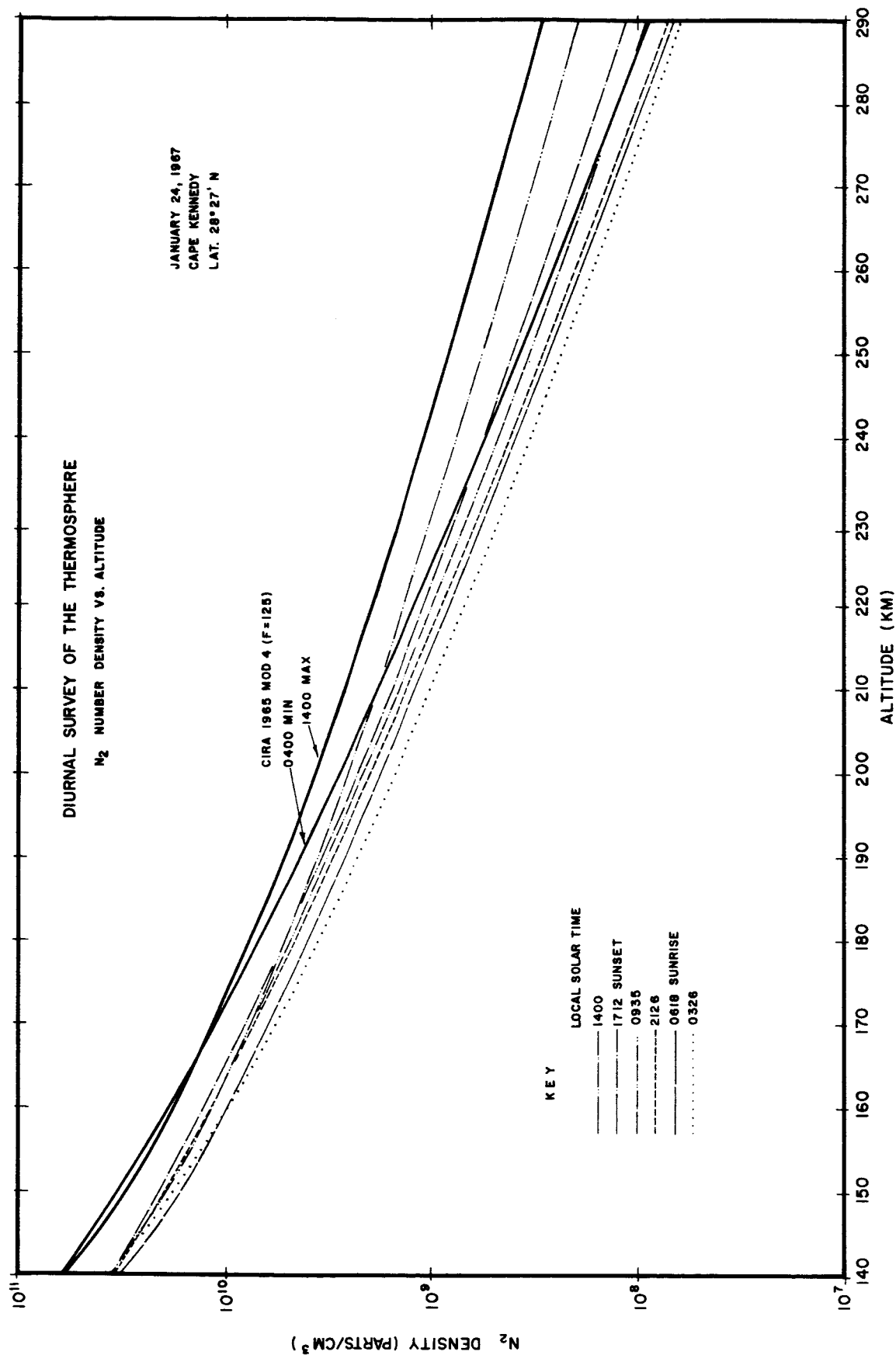


Figure 52. N₂ density vs. altitude.

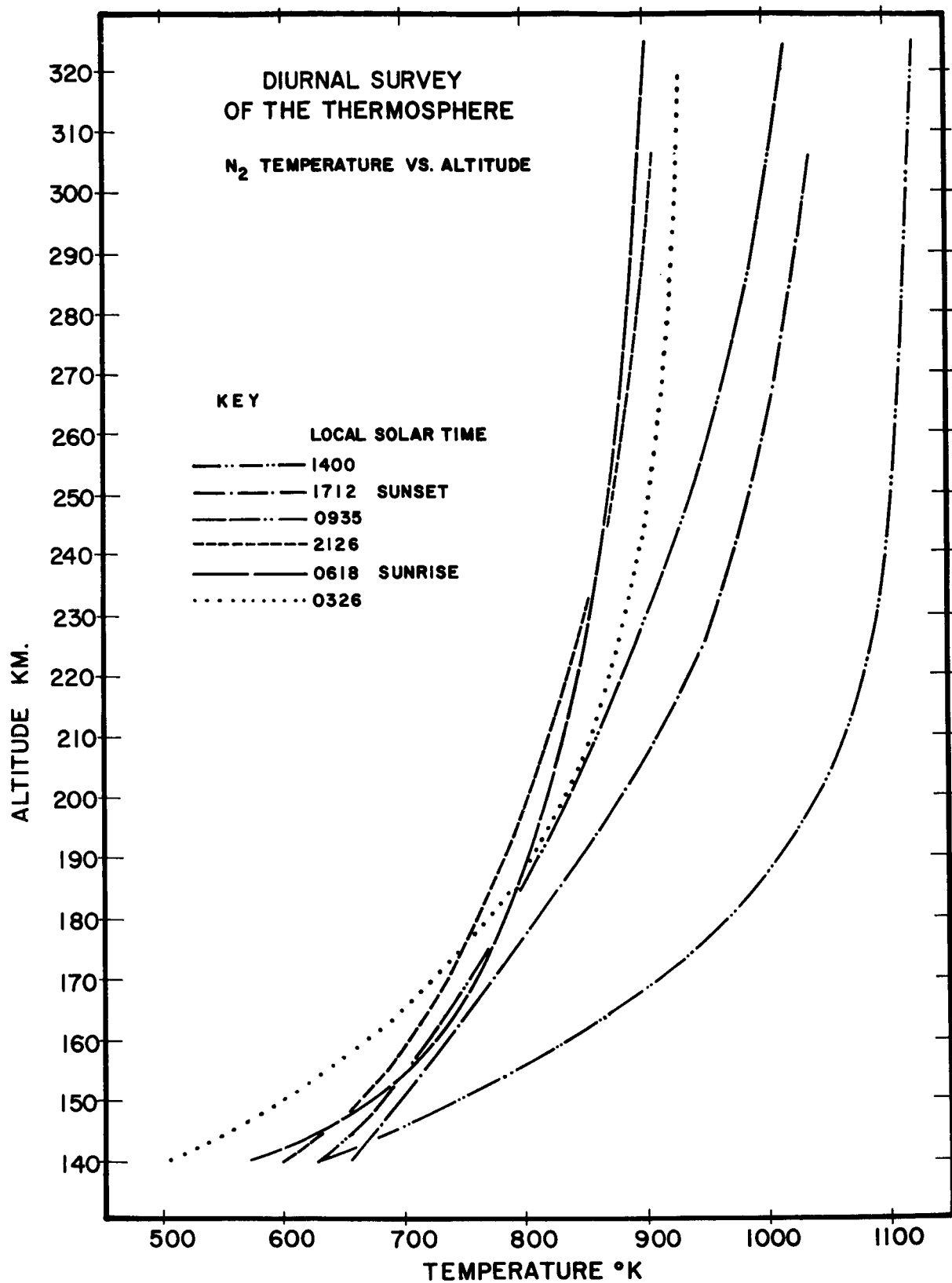


Figure 53. N₂ temperature vs. altitude.

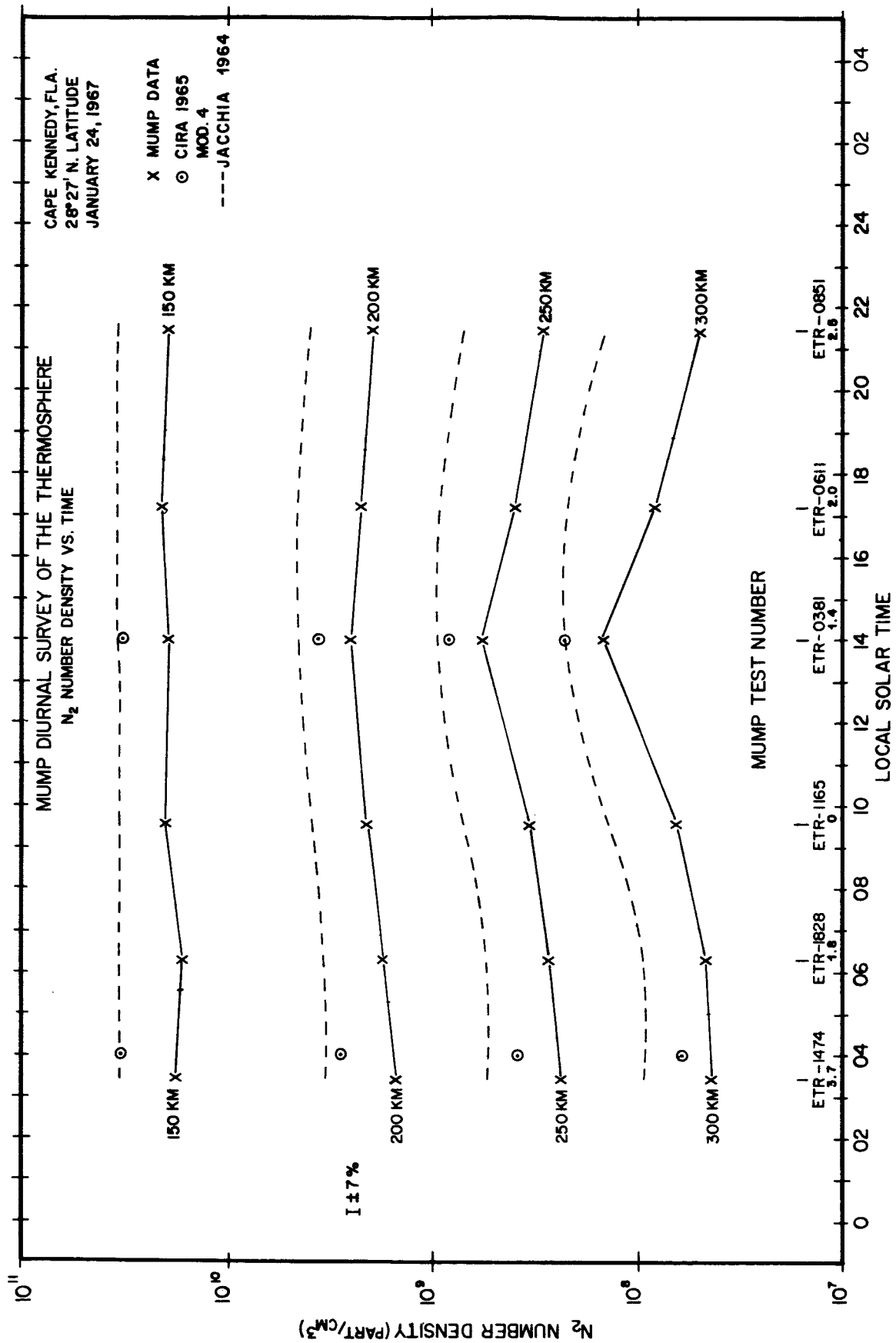


Figure 54. N₂ density vs. local solar time.

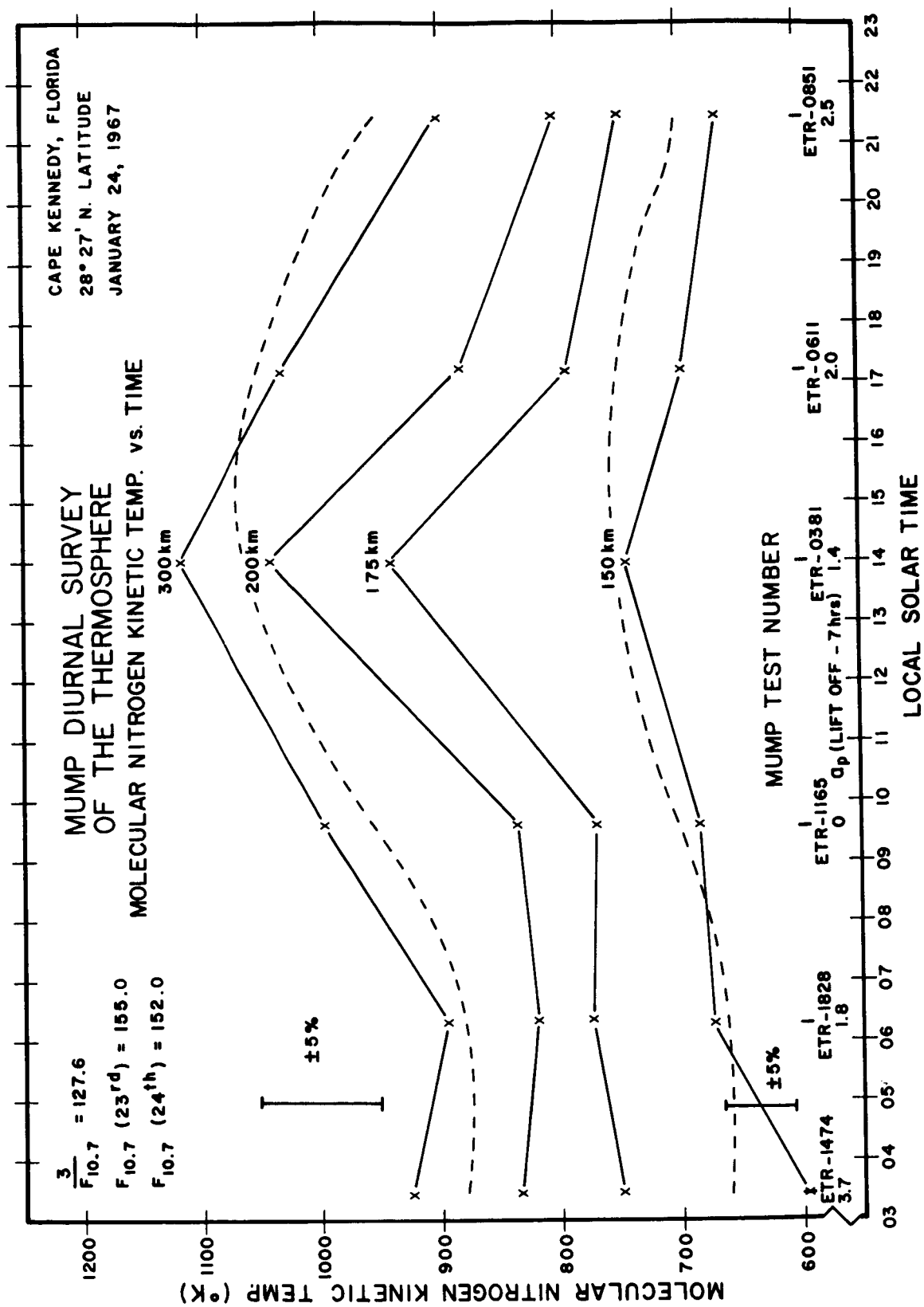


Figure 55. N₂ temperatures vs. local solar time.

9.2 CHARGED PARTICLE TEMPERATURE AND DENSITY

The electron temperature and density results obtained from the Langmuir probe experiments were shown in Figures 41 through 48. The ion temperatures shown in these figures were calculated by using the following expression given by Dalgarno, *et al.*, (1967), which is based on the assumption that only O^+ ions are present:

$$T_i = T_n + \frac{5 \times 10^{-7} (T_e - T_n)}{T_e^{3/2}} n_e^2 \quad (4)$$

$$\left\{ \frac{5 \times 10^{-7} n_e^2}{T_e^{3/2}} + n_e [9 \times 10^{-14} n(O) + 6 \times 10^{-14} n(N_2) + 6 \times 10^{-15} n(He)] \right\}^{-1}.$$

All the quantities which appear in this equation were measured simultaneously except $n(O)$ and $n(He)$. The values used in the calculations for the oxygen density were obtained from Jacchia's (1965a,b) model and the effect of neglecting helium was found to be negligible at these altitudes. Figure 56 shows the diurnal variation of the electron temperature T_e at the various altitudes, as measured by the Langmuir probes on January 24, 1967. The pre-sunrise effect in T_e is clearly shown by these results. The average rate of pre-sunrise temperature rise at 300 km is about $4^\circ K/min$ which is of the same order as the value given by Carlson (1966). A significant rise in the electron temperature was also present at sunset on this day, as may be seen from Figure 56. The rate at which energy is transferred from the electron gas to oxygen ions and which is approximately equal to the rate of energy input to the electrons, was calculated using equation (5) and plotted in Figure 57.

$$L_{ei} = \frac{5 \times 10^{-7} (T_e - T_i)}{T_e^{3/2}} n_e^2 \quad eV \text{ cm}^{-3} \text{ sec}^{-1}. \quad (5)$$

The calculations clearly indicate that the energy input varies smoothly; the sunset peak in T_e is apparently caused by a rate of decrease in the electron density which was somewhat larger than usually observed. The cooling rates calculated by Dalgarno, *et al.*, (1967) for a similar flight in November, 1963, are also shown in Figure 57 for comparison. A similar sunset peak was recently observed at Arecibo and reported by Wand at the University of Illinois Thomson Scatter Conference.

The results of the sunrise flight (ETR 1828) were shown in Figure 46; the changing solar zenith angles during the flight were also indicated. It is interesting to note that, although the electron density changed considerably during the flight, no detectable change in T_e was observed. This behavior can be explained by a rate of increase in the electron density which is of the right order to offset the increase in the heat input, resulting in no significant change in the electron temperature.

Thomson scatter measurements of the electron and ion temperatures were also made on January 24 by the Millstone Hill Radar Facility and the Jicamarca Radar Observatory. Figure 58 shows both the rocket and Thomson scatter results. The ion temperature results obtained from Jicamarca are in good agreement with the results obtained from the rocket data; the ion temperature results from Millstone are, however, lower than would be expected. There is only a gross agreement between the Millstone and Cape Kennedy T_e results shown in Figure 58, but this is reasonable, since electron temperatures exhibit significant spatial variations.

The comparison between the results of the April daytime flight and the preliminary backscatter results from Jicamarca, Arecibo, and Millstone are shown in Figure 59. There is good agreement between the ion temperatures obtained from the rocket data and those measured by Jicamarca and Arecibo; however, the results from Millstone are again low.

The preliminary analysis of the data obtained from these eight rocket flights has already improved our understanding of the diurnal behavior of the upper atmosphere; these series of flights have also provided an excellent opportunity to compare the results of rocket-borne measurements with those obtained by Thomson scatter technique.

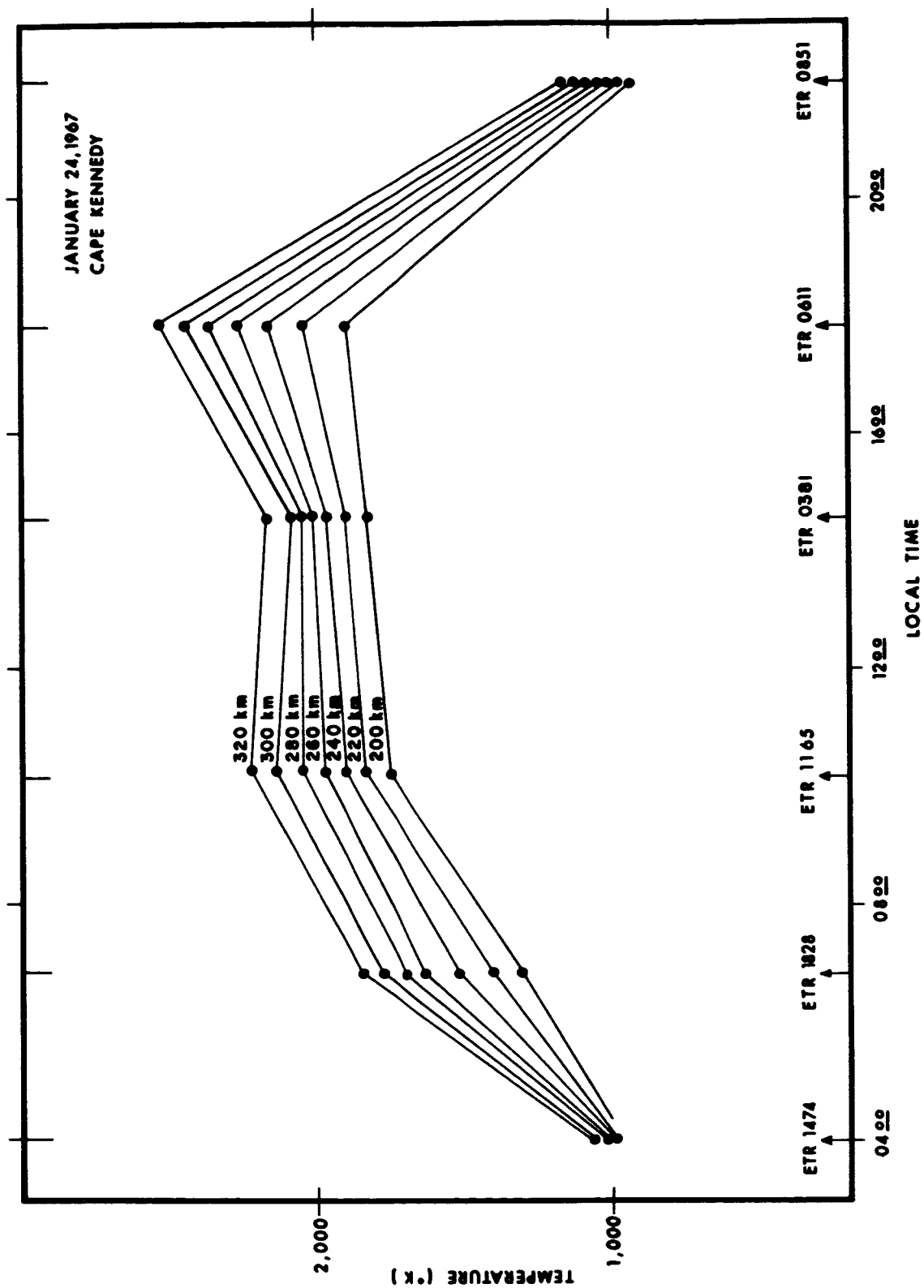


Figure 56. Diurnal variation of the measured electron temperatures.

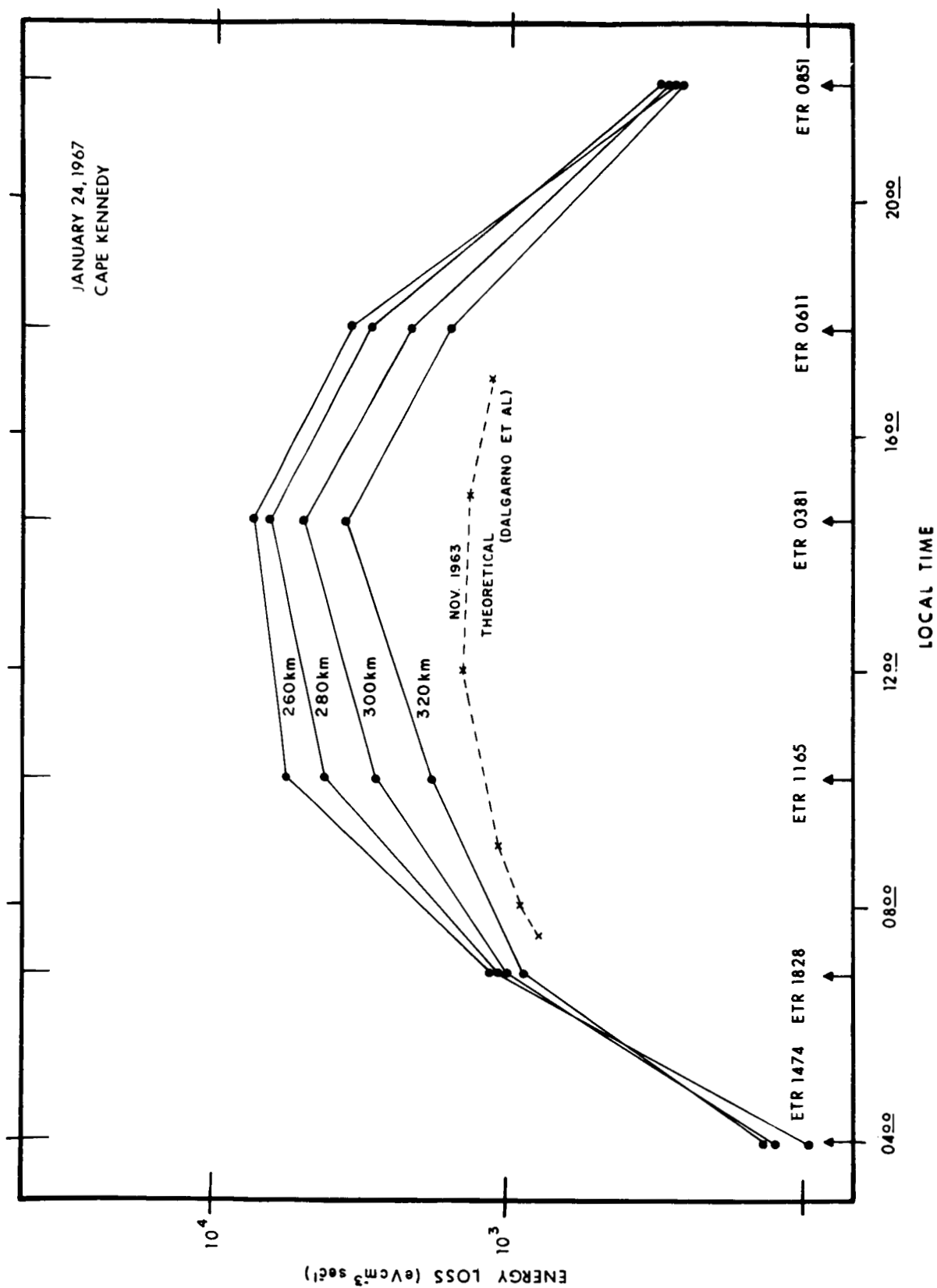


Figure 57. Diurnal variation of the calculated electron energy loss rates.

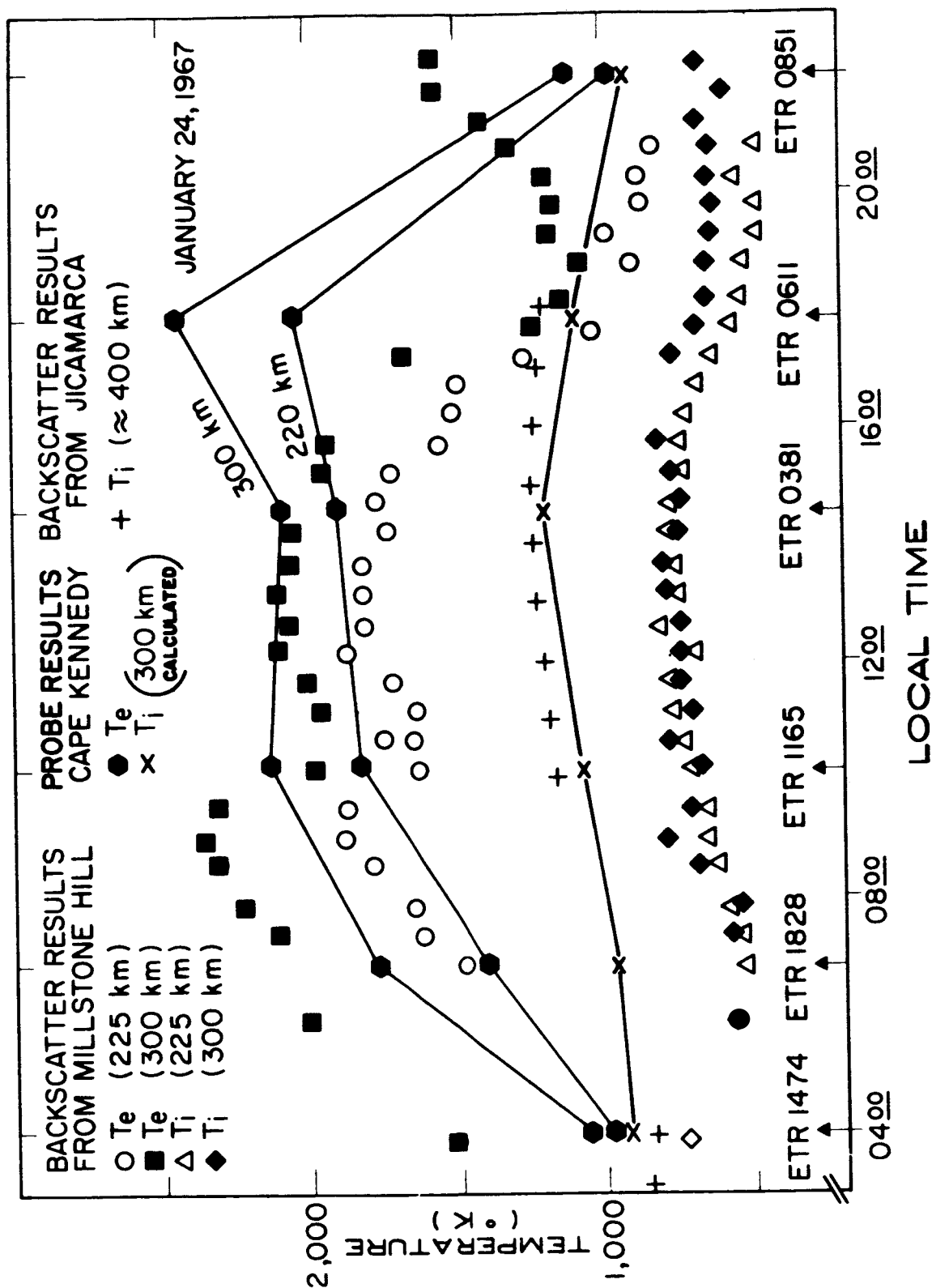


Figure 58. Comparison between the charge particle temperatures measured by the Langmuir probe and the ones obtained by Thomson scatter measurements (January 24, 1967).

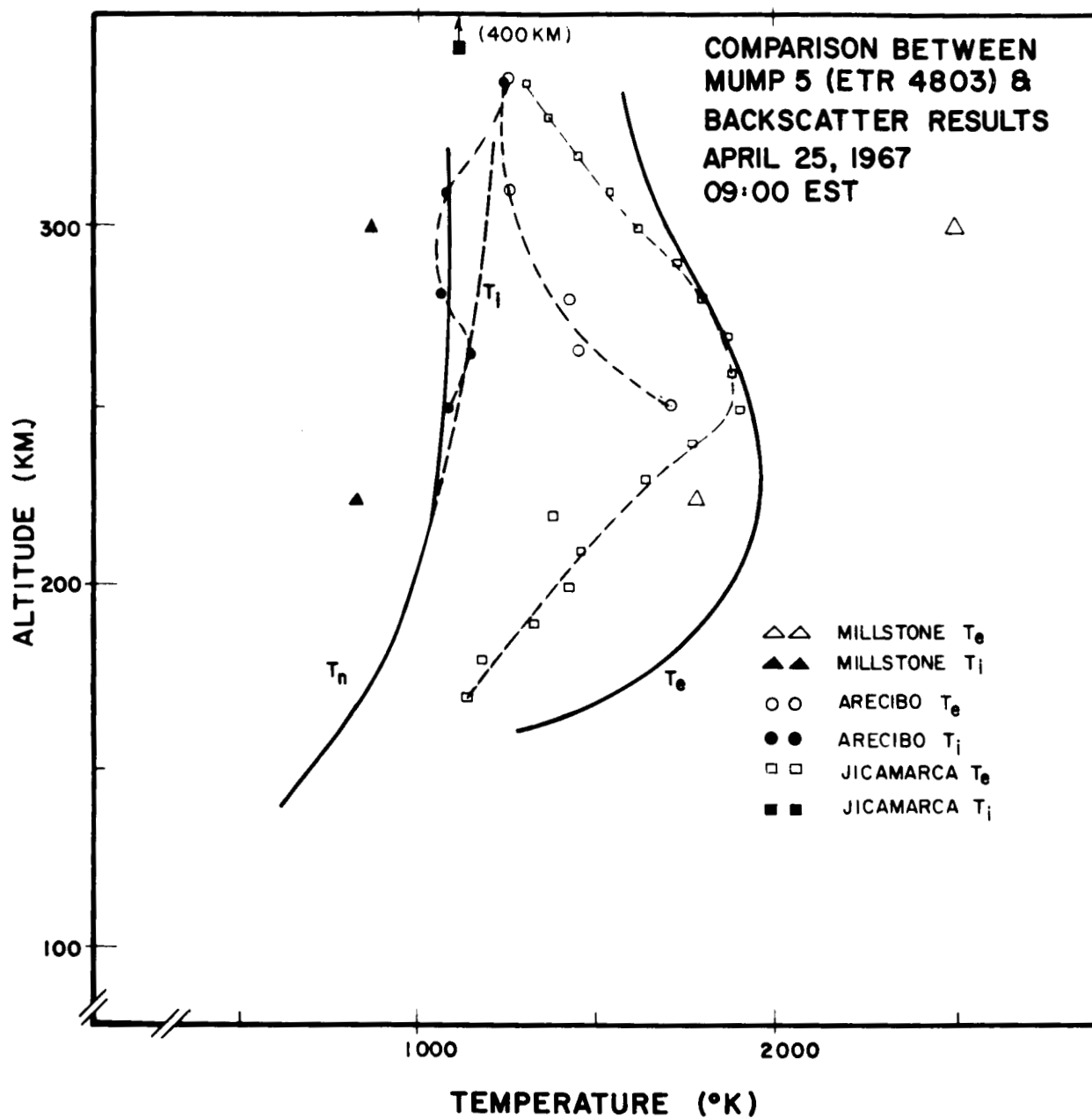


Figure 59. Comparison between the charged particle temperatures measured by the Langmuir probe and the ones obtained by Thomson scatter measurements (April 25, 1967).

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APPENDIX

DETERMINATION OF THE TOTAL PAYLOAD MOMENTS OF INERTIA

SYSTEMS TEST DEPARTMENT

REPORT NO. TR- 1219
LR NO. 2403

REPORT NO. TR- 1219 DATE 2 Feb 66

PERFORMED FOR: University of Michigan
2455 Hayward
Northwood Campus
Ann Arbor, Michigan

TEST: Moment of Inertia Determination

ITEM: Thermosphere Probe MUMP-1

TEST DATE: 17 Jan 66

PERFORMED AT: Space Laboratories

WORK ORDER NO: 85191-441-01-2403

AUTHORIZATION: PO R-64522

REQUESTED BY: Otto Kruse

REPORT SENT TO: John Maurer

PREPARED BY:

R. W. Hyde

R. W. Hyde
Test Engineer
Systems Test Department

APPROVED BY:

R. H. Culpepper

R. H. Culpepper
Project Engineer
Systems Test Department

ed



TR 1219

INTRODUCTION

The mass moments of inertia of a Thermosphere Probe MUMP-1, manufactured by the University of Michigan, were determined experimentally on the trifilar test stand. The purpose of the tests was to determine the mass constants about the spin axis as the split halves were placed at various angles. The mass constants were also determined for the test item in the lateral axis and the instrument package alone.

SUMMARY OF RESULTS

The moments of inertia of the test items are shown below.

	<u>lb ft sec² = slug ft²</u>
Payload about the spin axis	0.2135
Payload halves open 7.73 in. (spin axis)	0.4732
Payload halves open 18.67 in (spin axis)	1.3413
Payload halves open 42.25 in. (spin axis)	5.8871
Payload halves open 72.675 in. (spin axis)	13.7881
Payload halves horizontal	16.3455
Payload about the lateral axis	7.9402
Instrument package about spin axis	0.07035
Instrument package about lateral axis	1.0018

Payload total weight 120 lbs

Instrument package weight 48.75 lbs

METHODS AND DATA

The test items were mounted on the trifilar pendulum apparatus as shown in Figures 1 through 3 and the platform was allowed to oscillate through approximately 1 to 2 inches. The period of oscillation of the combined test item and platform was determined. At the conclusion of testing the period of oscillation of the platform alone was determined.

$$I_{\text{test item}} = I_{\text{combined test item and platform}} - I_{\text{platform alone}} \quad \text{or}$$

$$I = \frac{w_t a_t^2 p_t^2}{4 \pi^2 L} - \frac{w_p a_p^2 p_p^2}{4 \pi^2 L}$$

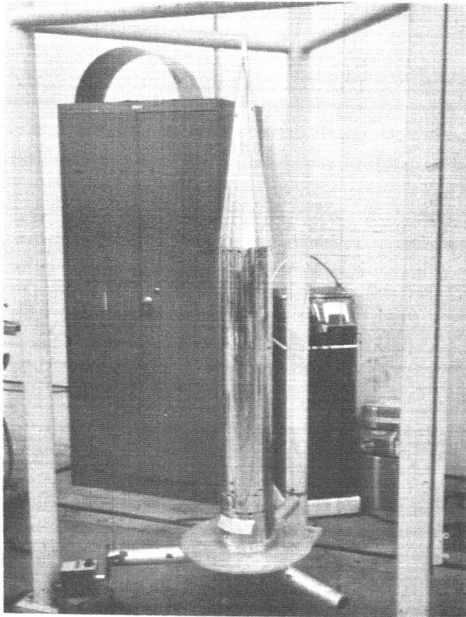


TR 1219

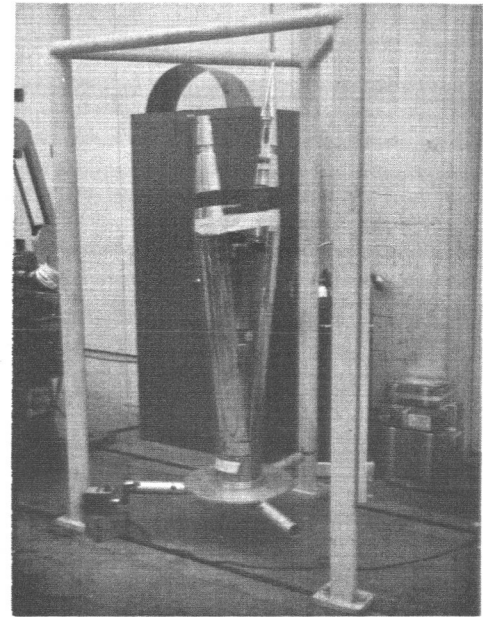
Where: w_t = Platform plus test item weight
 a = 20 inches
 L = Filament length, 108.22 inches
 w_p = Platform weight, 22 lbs
 P_t = Period in seconds, combined test item and platform
 P_p = Platform period in seconds, 1.49925
 I = Test item moment of inertia in lb in sec²

The tests were witnessed by J. Maurer, L. Degener, and R. Simmons of the University of Michigan. The test items were returned to the University of Michigan by the University of Michigan personnel.

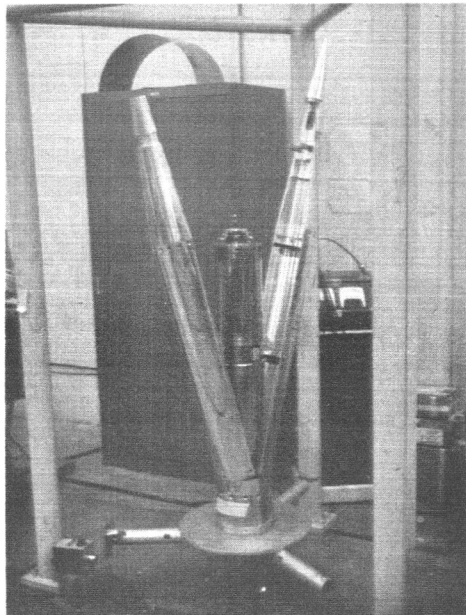
TEST SETUP



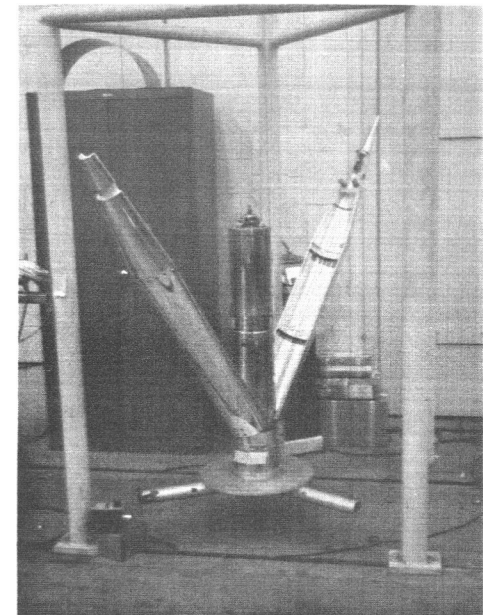
Shell Closed



Shell Open 7.73 inches

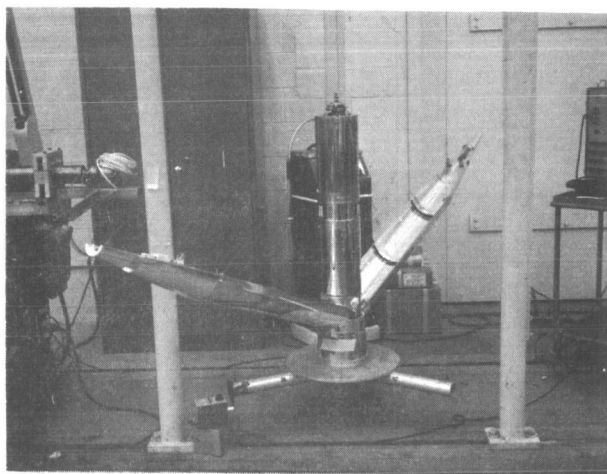


Shell Open 12.850 inches

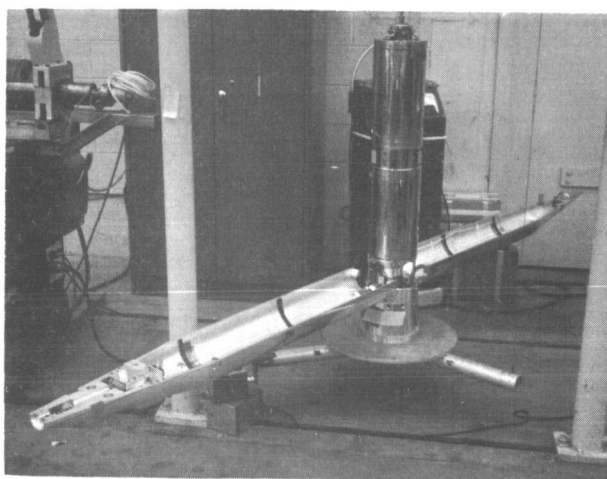


Shell Open 18.67 inches

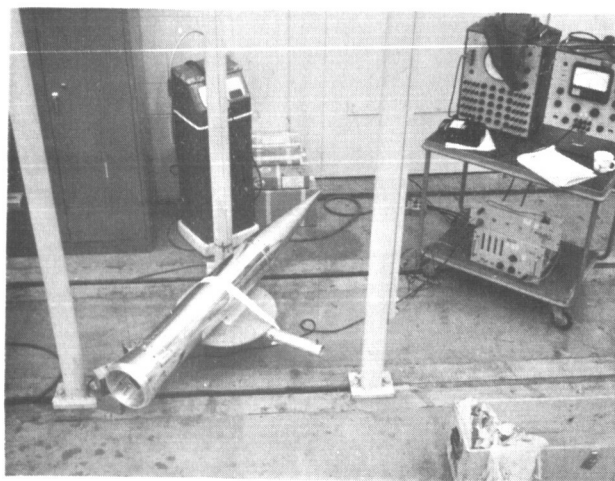
TEST SETUP



Shell open 72.675 inches

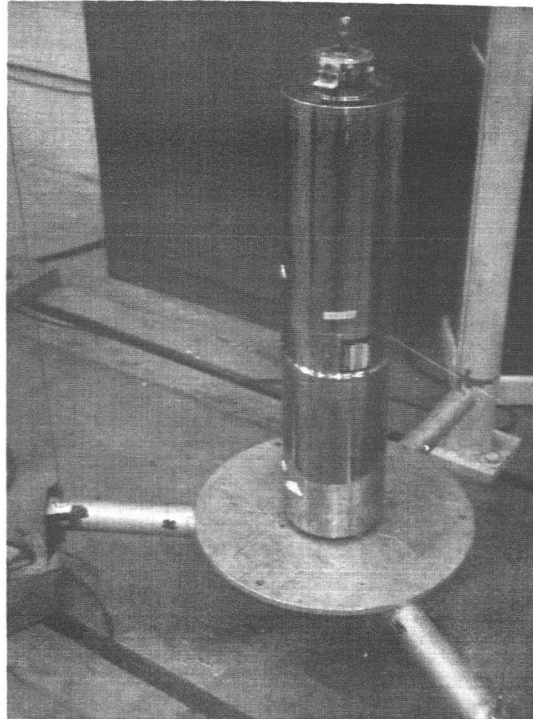


Shell fully open

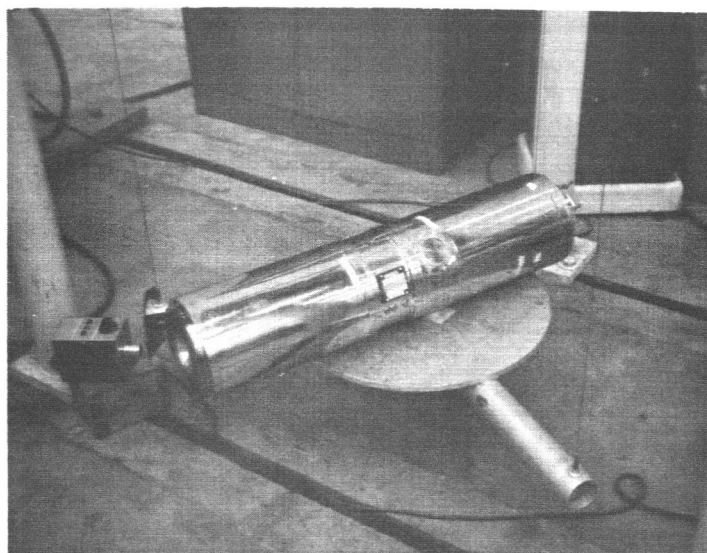


Lateral axis

INSTRUMENT PACKAGE TEST SETUP



Spin Axis



Lateral Axis

SYSTEMS TEST DEPARTMENT

TEST EQUIPMENT

Test: Moment of Inertia

Date Used: 17 Jan 66

Test Item: Thermosphere Probe

[illegible]